THE EFFECTS OF PROJECT DELIVERY SYSTEMS ON PROJECT PERFORMANCE

BY

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A Thesis Presented to the
DEANSHIP OF GRADUATE STUDIES

KING FAHD UNIVERSITY OF PETROLEUM & MINERALS
DHAHRAN, SAUDI ARABIA

In Partial Fulfillment of the
Requirements for the Degree of

MASTER OF SCIENCE

In

CONSTRUCTION ENGINEERING AND MANAGEMENT

MARCH 2014

KING FAHD UNIVERSITY OF PETROLEUM & MINERALS

DHAHRAN, SAUDI ARABIA

DEANSHIP OF GRADUATE STUDIES

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DEDICATION

I dedicate this work to the men and women of the construction industry.

ACKNOWLEDGEMENTS

Acknowledgement is due to the King Fahd University of Petroleum and Minerals for support of this research.

Acknowledgement is due to the project Owner for allowing the use of their data.

I express special recognition to Dr. Abdulaziz Bubshait, Thesis Committee Chairman; Dr. Mohammed Al-Khlail, and Dr. Mohammad Hassanain thesis committee members as true educators, for their constructive guidance.

I express thankful recognition to Dr. Sadi Assaf, who served as Academic Advisor for his watchful guidance and oversight. Especially for founding the Master of Construction Engineering & Management degree program at the King Fahd University of Petroleum & Minerals.

I express gratitude to Dr. Masen Al-Sinan for encouraging the pursuit of advanced degrees.

I express gratitude to Dr. Robert Johnston whose continuous enthusiastic encouragement, interest, and expert consultation provided tremendous value to this research.

To my role models, Mother and Daddy, I owe my confidence to your parenting. Thank-you for teaching me discipline, responsibility, respect, diligence, honor, and the value of hard work.

Most importantly to my beloved wife Ms. Donna, I owe my eternal love, gratitude, devotion and accomplishments. Thank you for supporting this research and teaching me the power of love.

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THESIS ABSTRACT

NAME:	JOHN C. MOSLEY, Jr.
TITLE:	The Effects of Project Delivery Systems on Project Performance
MAJOR FIELD:	Construction Engineering and Management
DATE OF DEGREE:	March 2014

While literature on design-bid-build (DBB) and design-build (DB) project delivery systems is plentiful, this is not the case for studies based in Saudi Arabia. Data on 292 projects geographically distributed throughout the Kingdom were collected from one of Saudi Arabia's largest project owners. The purpose of this thesis is to study the relationship between project performance and the delivery system used to execute them. To achieve this purpose an objective of statistically quantifying the effects that project delivery systems have on performance was established through analyzing 13 indicators being: management / administration, equipment / facilities, subcontracting, planning / scheduling, quality program, technical competence / workmanship, material procurement, cost control safety, loss prevention, cost growth, schedule growth, and change order rate. The hypothesis that design-build and design-bid-build delivery systems perform equally was tested by means of the Student's t-test, the results were compared to other published studies having similar research objectives. This study uniquely contrasts the existing body of knowledge consisting predominantly of U.S. projects and contractors to Saudi Arabian projects. Another unusual aspect of this investigation is a rare insight into the performance of Saudi owned construction companies based on an infrequently used combination of performance indicators. The results show overall the traditional design-bid-build delivery system out performs design-build. Statistically significant differences in two of the objective performance indicators measured, cost growth and change order rate, to be in favor of DB while DBB schedule growth scores were found to be lower than DB indicating better performance. Based simply on observed differences in 7 of the 10 subjective indicators, performance was found better for the DBB delivery system. Project delivery system did not seem to have an effect on 2 indicators and the remaining indicator (quality) returned a score in favor of the DB delivery system.

الملخص

بينما الأدب في التصميم والبناء في محاولة (DBB) والتصميم والبناء (DB) نظم
تسليم المشروع وفيرة ، وهذا ليس هو الحال بالنسبة للدراسات ومقرها في المملكة
العربية السعودية . تم جمع البيانات عن المشاريع 292 موزعة جغرافيا في جميع أنحاء
المملكة من واحدة من أكبر أصحاب المشاريع في المملكة العربية السعودية . والغرض من هذه
الرسالة هو دراسة العلاقة بين أداء المشروع ونظام التوصيل المستخدمة لتنفيذها .
لتحقيق هذا الغرض و الهدف من قياس إحصائيا الآثار التي نظم تسليم المشروع على أداء
تأسست من خلال تحليل 13 مؤشرا هي: إدارة / الإدارة ، والمعدات / المرافق والتعاقد من
الباطن ، والتخطيط / الجدولة ، برنامج الجودة والكفاءة الفنية / صنعة ، المواد المشتريات
والتكلفة سلامة السيطرة والوقاية من فقدان والنمو التكلفة ، والنمو والجدول الزمني،
وتغير معدل النظام. الفرضية القائلة بأن التصميم والبناء و التصميم والبناء المزايدة
نظم تسليم يؤدون بالتساوي تم اختباره عن طريق اختبار t الطالب، و تمت مقارنة
النتائج إلى دراسات أخرى منشورة وجود أهداف بحثية مماثلة . هذه الدراسة تتناقض بشكل
فريد الجسم موجود من المعرفة التي تتكون في الغالب من مشاريع الولايات المتحدة
والمتعاقدين لمشاريع في المملكة العربية السعودية . وهناك جانب آخر غير عادية من هذا
التحقيق هو نظرة نادرة إلى أداء شركات المقاولات المملوكة لسعوديين على أساس مزيج
القليلة استخدام مؤشرات الأداء. وتبين النتائج أن التصميم المزايدة والبناء هو نظام
تسليم أفضل لبناء المشاريع في بيئة البناء في المملكة العربية السعودية فريدة
من نوعها.

CHAPTER 1

INTRODUCTION

1.1 Introduction

There exist two basic categories of construction Project Delivery Systems; those which combine project design with construction under one contract and those which separate the design and construction functions into two or more contracts. “Project delivery systems define the roles and responsibilities of the parties involved in a project. They also establish an execution framework in terms of sequencing of design, procurement, and construction” (Oyetunji and Anderson 2006). “Currently, no single project delivery system is most appropriate for any kind of project. Instead, combinations of different strategies are used for different circumstances” (Ibbs, et al. 2003). As Moavenzadeh and Wolff (2006) pointed out, there are as many variations of project delivery systems as fertile minds of marketers and financiers can conceive. “Achieving a quality project on time and within a specified budget is the goal of all owners. Although effective selection of the project participants and proficient execution of the project are important, selecting the optimum method of execution (the project delivery selection) is critical” (CII 1997).

The Kingdom of Saudi Arabia's geopolitical and economic structures differ from other global economies, which provide a unique construction environment, to which there is no significant amount of published research. In 2012 the Kingdom's construction industry was valued at 27.1 billion USD, equating to 4.3% of the gross domestic product (GDP) employing 5.3% of the total labor force, and making up 40% of the total awarded construction projects in the region. "The total value of contracts issued in the Kingdom's construction sector grew by 50% in 2012, following a 140% year-on-year increase in contract awards during 2011" (BMI 2013). "The majority of these contracts are procured by government or semi government institutions, as part of the country's implementation of its Ninth Development Plan, which forecast public spending of almost USD 385B between 2010 and 2014" (BMI 2013). "In an economy where the government is largely responsible for generating the state's entire GDP, any budget delays cause a significant negative chain-reaction with non-payments to contractors. An issue increasingly raised by industry participants, even those *favored* by the government" (BMI 2013).

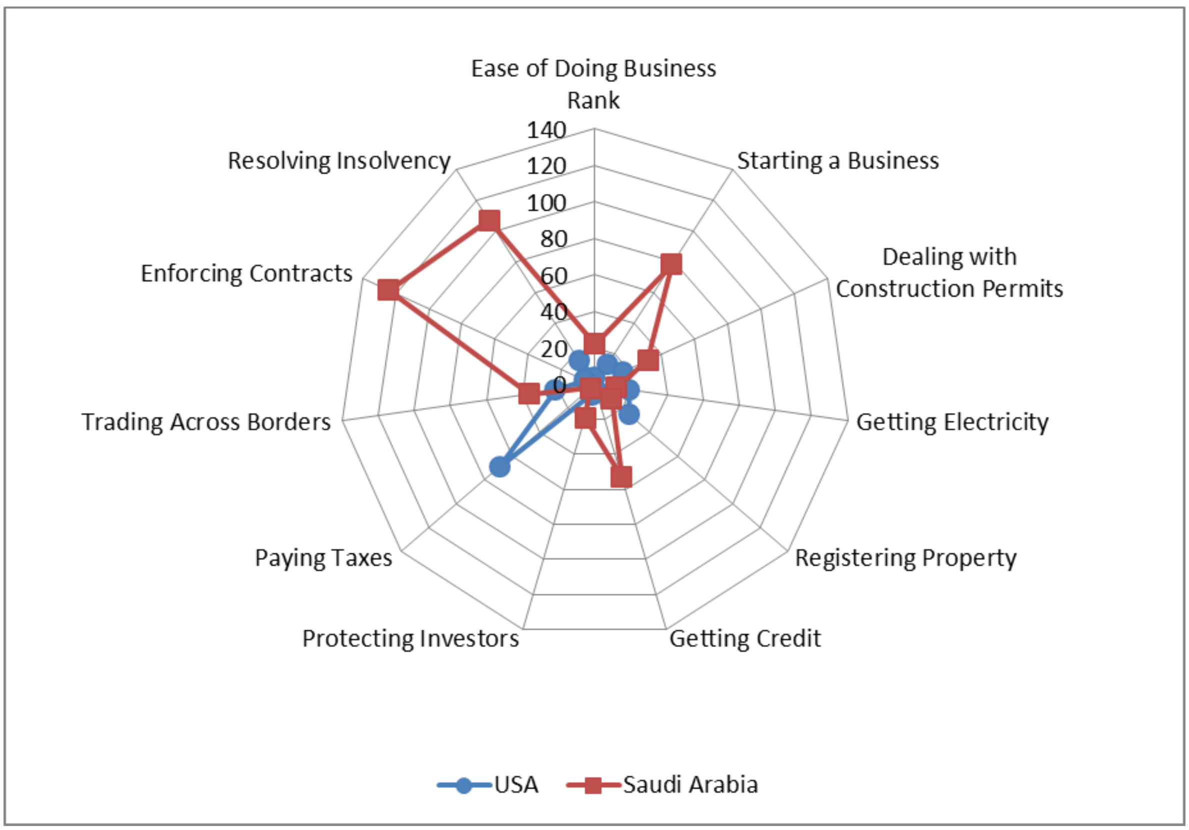
Saudi Arabia ranked twenty second out of one hundred eighty three economies studied by the World Bank on ease of doing business contrasted with the United States whose ranking is fourth. The 11 economic indicators "measure business regulation and protection of property rights and their effect on businesses…by complexity of regulations; time and cost of achieving a regulatory goal or complying with regulation; the extent of legal protections of property; tax burden on business; and employment regulation” (World Bank 2013).

Table 1 Top 25 Economies Ranked by Ease of Doing Business

Economy	Ease of Doing Business	Starting a Business	Construction Permits	Getting Electricity	Registering Property	Getting Credit	Protecting Investors	Paying Taxes	Trading Across Borders	Enforcing Contracts	Resolving Insolvency
Singapore	1	4	2	5	36	12	2	5	1	12	2
Hong Kong	2	6	1	4	60	4	3	4	2	10	17
New Zealand	3	1	6	32	2	4	1	21	25	17	13
United States	4	13	17	19	25	4	6	69	22	6	16
Denmark	5	33	8	14	6	23	32	13	4	34	10
Norway	6	43	23	14	7	70	25	19	21	4	3
United Kingdom	7	19	20	62	73	1	10	16	14	21	8
Korea, Rep.	8	24	26	3	75	12	49	30	3	2	14
Georgia	9	7	3	50	1	4	19	33	38	30	81
Australia	10	2	11	36	37	4	70	48	44	15	18
Finland	11	49	34	21	24	40	70	23	6	9	5
Malaysia	12	54	96	28	33	1	4	15	11	33	49
Sweden	13	54	25	9	35	40	32	38	8	27	22
Iceland	14	45	40	1	9	40	49	41	82	3	11
Ireland	15	10	106	95	53	12	6	6	28	63	9
Taiwan, China	16	16	9	6	32	70	32	54	23	90	15
Canada	17	3	69	152	54	23	4	8	44	62	4
Thailand	18	85	16	10	26	70	13	96	20	23	58
Mauritius	19	14	62	44	60	53	13	12	15	58	64
Germany	20	106	14	2	81	23	100	72	13	5	19
Estonia	21	47	35	52	14	40	70	50	7	31	72
Saudi Arabia	22	78	32	12	12	53	19	3	36	124	107
Macedonia	23	5	65	101	50	23	19	24	76	59	60
Japan	24	114	72	27	64	23	19	127	19	35	1
Latvia	25	59	113	83	31	4	70	52	16	24	33

Source: World Bank (2013) Doing Business database

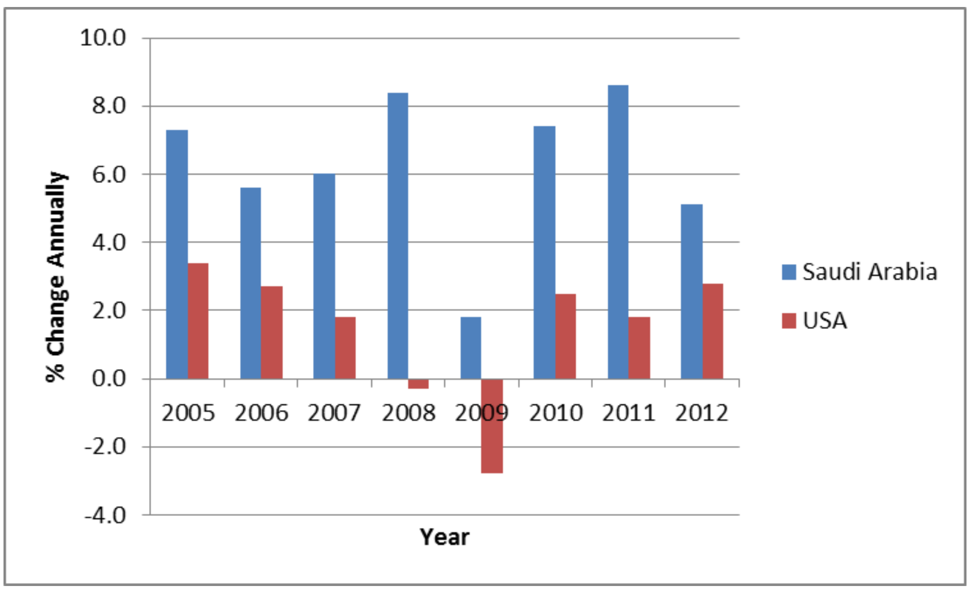
Although from Table 1 it is easy to see the Saudi economy is unique, the United States was chosen to contrast the Saudi Arabian economy against due to several published reports with similar objectives to this study primarily based on U.S. projects. Differences between the being United States and Saudi Arabian economies ranked on ease of doing business are illustrated by Figure 1 below:



Data Source: World Bank (2013) Doing Business database

Figure 1 Ease of Doing Business Comparison

Another economic difference as defined by the International Monetary Fund (IMF) which classifies the Saudi economy as "developing" and the United States as an "advanced economy" (IMF 2013). The IMF also report differences between the Saudi real gross domestic product (GDP) annual growth being greater than that of the United States as represented in Figure 2.



Data Source: IMF (2013) World Economic Outlook

Figure 2 Real GDP Annual Percentage Change

1.2 Research Purpose

The effective selection of a project delivery system may impact the success of project completion as Oyetunji writes:

> The suitability of the project delivery system selected for a project greatly influences the efficiency with which the project is executed and thus constitutes a critical success factor. As such, decision making in selection of project delivery systems should be based on consideration of objective quantitative metrics applied in an analytical evaluation of alternatives. However, because quantitative data required for analytical evaluation of alternatives have not been available, delivery systems are currently selected in most cases based on non-quantitative approaches (Oyetunji and Anderson 2006).

The purpose of this thesis is to study the relationship between project performance and the delivery system used to execute them in the Saudi Arabian construction environment.

1.3 Research Objective

The objective of this research is to statistically quantify the effects that project delivery systems have on project performance. The definition of project performance varies widely. Of the many published performance indicators, 13 have been selected for this study which reflect the owner's measure of project health, consisting of: (1) management / administration, (2) equipment / facilities,

(3) subcontracting, (4) planning / scheduling, (5) quality program, (6) technical competence / workmanship, (7) material procurement, (8) cost control (9) safety, (10) loss prevention, (11) cost growth, (12) schedule growth, and (13) change order rate. These specific indicators may mirror problem areas based on the owner's past experience or behavior traits the owner would like to encourage in the future.

To accomplish this objective, the hypothesis that design-build and design-bid-build delivery systems perform equally, will be tested. The test results will then be compared to studies with similar research objectives.

1.4 Research Limitations

The scope of this study focuses on conducting a quantitative analysis based on data gathered from a single owner. Although the projects studied are geographically distributed throughout the Kingdom and are diversified in nature, caution should be used when interpreting the results as representative of the Saudi Arabian construction industry as a whole, due to the Owner's project execution policies, procedures, and standards as well as the level of enforcement of those practices may differ from other owners. The lack of information identifying the cause of contract change orders, whether owner driven or contractor initiated, limits the interpretation of the findings. Sample sizes in some of the test criteria were statistically small thus limiting the reliability or confidence level of the analysis for those samples.

CHAPTER 2

RELATED LITERATURE

2.1 Introduction

While some delivery systems may be better suited than others for the Saudi Arabian construction contracting environment, the Design-Build and Design-Bid-Build delivery systems have a proven history and are two of the most commonly used (CII 2004).

Every delivery system includes planning to some degree, design, and construction. Some systems reach beyond these bounds to include financing, commissioning, operations, ownership, leasing, and maintenance. "Indeed recent research has outlined twelve distinct project delivery systems" (CII 2004). While definitions of project delivery systems vary throughout the industry selecting the correct delivery system hinges on answering three questions:

"1. Does the Owner want to separate design and construction? 2. Does the Owner want to have a commissioning period before project turn over to assure functionality? 3. Does the Owner want an extended operational period?” (Moavenzadeh and Wolff 2006)

In addition to DB and DBB other generally recognized primary project delivery systems are multiple primes, build / operate / transfer (BOT), alliance, and construction management at risk / construction management general contractor.

2.2 Design-Bid-Build

Design-Bid-Build abbreviated DBB is a construction project delivery system which separates the design and construction functions and is considered the most widely accepted delivery system used today (Ibbs, et al. 2003). Commonly named, the traditional delivery system, Design-Bid-Build consists of three distinct main phases; design, bidding or tender, and construction phases with clear lines defining the rolls and responsibilities of the project participants. Two prime contracts are held by the owner, one with the construction contractor and the other with the designer (Rojas and Kell 2008). For the purposes of this study Procure-Build, Multi-Primes, Construction Manager at Risk, General Contractor at Risk, Design-Construction Manager, and their several variations will be grouped under Design-Bid-Build.

During the design phase if the owner does not have in-house design capability, the services of an architect / engineer may be retained to design and produce complete design documents which the construction contractors will offer their bid and ultimately be used to construct the project.

Depending on the project type the owner may choose to retain an architect as the primary design agent who in turn will retain the services of other professionals and consultants including fire protection, civil, mechanical, plumbing, electrical, and structural engineers; landscape and interior design architects to develop the bid documents consisting of drawings, specifications, and the scope of work. In the case of an industrial or heavy civil project the owner may choose an engineering firm as the primary design agent, who in turn will procure architectural services if needed. In either case the architect / engineer is a separate entity and is not party to the construction contract, where responsibility and authority are derived from the contract with the owner. Therefore, there exists no contractual relationship between the designer and the construction contractor which allows the designer to act as the owner's agent during the construction phase with the best interest of the owner in mind.

As the owner's agent the designer commonly represents the owner during project construction, by acting on behalf of the owner in administering the day to day contract requirements. As such the designer advises and consults with the owner, is responsible for assuring the contract requirements are met, and the final facility meets the design intent.

The owner is responsible for drafting well-defined contract documents including scope of work, making timely decisions, selecting a qualified engineer / architect, and selecting a qualified construction contractor (CII 1997).

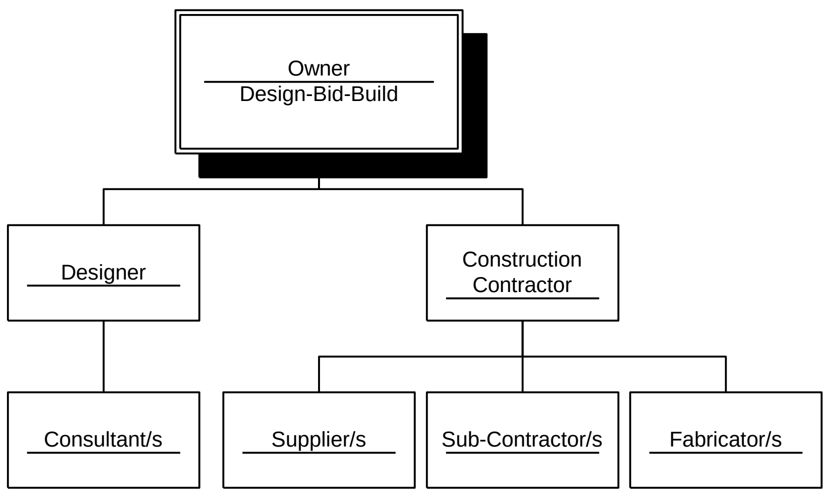


Figure 3 Typical Design-Bid-Build Delivery System

2.3 Design-Build

Design-Build (DB) is a system which combines the responsibilities of the designer and constructor sense the designer is an employee, sub-contractor, or partner of the construction contractor, and "may consist of a team or consortium" thus providing a single point of accountability to the Owner (Rojas and Kell 2008;

Molenaar, et al. 1999). For the purposes of this study Turnkey, Super Turnkey, Engineer / Procure / Construct (EPC), and their several variations will be grouped under Design-Build.

“Design-build offers an early knowledge of firm project costs, a single point of responsibility and the potential of a condensed design and construction schedule. Teamwork is critical to the success of a design-build project where traditional checks and balances are replaced by trust among team members and fair contracting” (CII 1997). The D-B contract is performance based not “prescriptive specification based” where the owner has little involvement in the project integration process between design and construction, therefore the owner’s expectations must be well defined before selection of the contractor (CII 1997).

Initially the design-build contractor involved a single firm holding the in house capabilities to provide complete project design, planning, and construction functions. With increased popularity individual engineering firms, construction contractors, and architectural firms sought to compete with the original DB contractors. Currently many arrangements exist to meet the project requirements including construction contractors retaining the services of an engineer / architect, or an engineer / architect firm subcontracting the construction to a construction contractor. “There are basically three types of design-build firms today: contractor-led, designer-led, and single firm” (Fisk and Reynolds 2010).

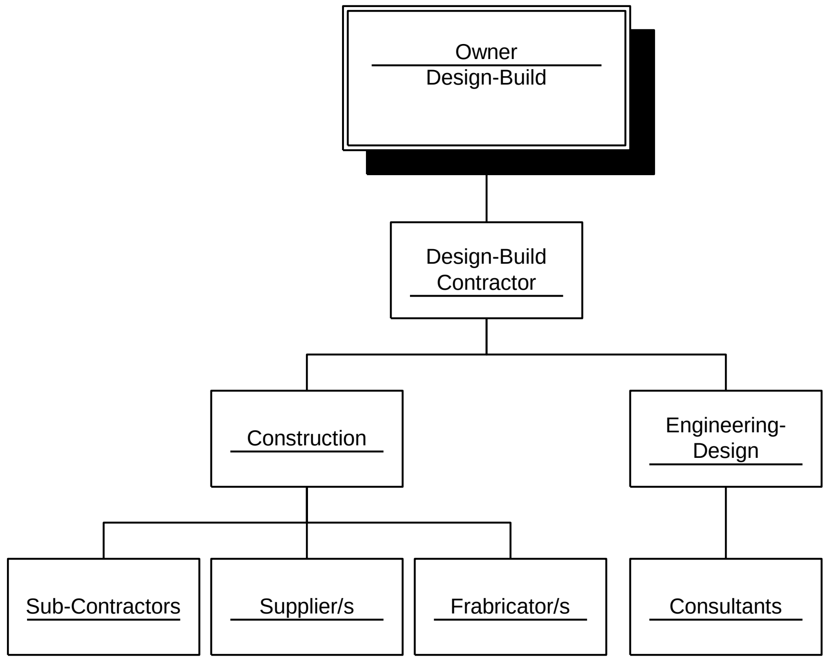


Figure 4 Typical Design-Build Delivery System

2.4 Comparative Studies

A review of the recienly published body of knowledge comparing DBB and DB project delivery systems reveals the following:

Minchin (2013) statisticaly analyzed a dataset of 30 BD and 30 DBB projects randomly selected from the Florida Department of Transportation (FDOT) United States of America. The projects were executed between 2002 and 2010 with values of $7MM and grater with most projects including both asphaltic highway pavement and bridge construction. The authors choose cost and duration as the performance factors to study. The cost factor had three components being original cost estimates, awarded bid amount and final cost. Data collected for project duration consisted of original contract duration and final duration.

A preliminary analysis of the dataset revealed "DBB projects performed significantly better in terms of cost and not quite as well in terms of duration. The preliminary arithmetic analysis indicated that the DBB method outperformed the DB method for contractors' performance in meeting contract cost and for the accuracy of preliminary cost estimates; the duration comparison among the systems showed minimal differences and a slight edge for DB" (Minchin Jr, et al. 2013). A statistical analysis including the Students t-test, independent samples t-test, Leven's test, Welch's test, and the nonparametric Mann-Whitney U test, were applied to the sample population with results largely confirming the preliminary findings that DBB "was more consistent and reliable in matters of cost than the DB method" (Minchin Jr, et al. 2013). The two delivery systems DBB and DB showed little difference when compairing the duration performance metric although, DB was found to be either the same or slightly better than DBB.

Rosner (2009) studied data related to 278 DB and 557 DBB United States Air Force military construction (MILCON) projects dated between 1996 and 2006 with the average dollar size being 6.9MM USD and the maximum project value being 87.5MM USD. The construction work ranged from airfield pavements to security facilities to air craft maintenance facilities and dormatories. “The historical design time for projects is 7 months for projects with a programmed amount less than \$5 million, 9 months for projects between \$5 and \$10 million, and 10 months for projects more than \$10 million. The corresponding criteria for construction duration is 365 days for projects with a programmed amount less than \$5 million, 540 days for projects between \$5 and \$20 million, and 730 days for projects more than \$20 million” (Rosner, et al. 2009).

The 6 project performance metrics studied by Rosner (2009) are cost growth, schedule growth, unit cost, modifications per million dollars, total project time, and current working estimate to programed amount ratio (CWE/PA). The unit cost metrix was developed by dividing the total project cost by total quantity of units constructed in m^2 adjusted for location and years. Cost growth expressed as a percentage is difference between the original and actual contract cost. Schedule growth was calculated by taking the difference between the contract notice to proceed and actual benificail occupancy dates divied by the difference between the notice to proceed and planned benificial occupancy dates and expressed as a percentage. The modifications per million dollars metric used by Rosner (2009) to measure the number of problems experienced on a project was defined by the number of contract modifications divided by the contrat value expressed in million dollars to normalize the effect of project size. Current working estimate to programed amount ratio consists of the total working estimate divided by the programed amount. Total project time is the difference between the time design starts and the facility is occupied and provides an indicator of which project delivery system is faster from start to finish.

Rosner (2009) found through application of the t test the DB delivery system performed better in 3 of the 6 performance metrix studied with significantly better performance for cost growth and number of modifications per million dollars. DBB performed significantly better in terms of total project time. Overall Rosner (2009) conculded “the DB method provided an advantage over the DBB method for *United States* Air Force MILCON projects”.

Hale (2009) concluded DB to be superior with regards to time and cost through a study of 38 DB and 39 DBB United States Navy MILCON projects. The projects selected for study are similar in design, bachelor enlisted quarters (BEQ) also called barracks or dormatories, producing a homogenius sample managed by a single entity.

For the DBB projects, the minimum and maximum project duration was 675 days and 3,160 days, respectively. For DB projects, the minimum and maximum project durations were 404 days and 1,078 days respectively. The average numbers of beds in DB were 329 and DBB projects were 275. For DBB projects the final project cost varied between $4,733,558 and $26,805,417 and for DB projects, the final project cost varied between $3,706,719 and $37,564,468.

Project duration, project duration per bed, project time growth, cost growth and cost per bed were analyzed by use of standard descriptive statistics and a single factor analysis of variance (ANOVA). Cost per bed with other costs is one of the performance indicators idetified by Hale (2009) consisting of BEQ construction including other types of work such as demolition, environmental mitigation, special architectural features to match surroinding buildings, dewatering, dining facilities, and parking structures. Contracted with the cost per bed performace factor where these other costs were removed “to accurately compare project with nonconstruction costs to projects without these extra costs” (Hale, et al. 2009). Cost growth was evaluated as a percentage of change in terms of total contract cost. The total project duration metric was measured from the start of design to contract completion for both DB and DBB reported in days and does not take into account the size of the project. Each project had a unique number of beds. The time per bed factor may be a more accurate indicator of project performance and is reported in days. Time growth studied by Hale (2009) is the number of days beyond the targeted completion date. Hale (2009) conculded that “while this sample is unique to NAVFAC, the results point out that the DB method is superior to DBB when used on building projects. The sample data show that DB projects will take less time to complete and have less time and cost growth”.

Riley (2005) studied 65 DB and 55 DBB projects with original contract values catigorized as small between \$50,000 and \$100,000; medium between \$100,000 and \$300,000; and large over \$300,000 cost categories with a total of 598 contract change orders performed by the same full service DB mechanical contractor. Cost growth expressed in percentage by is broken into two subsets (1) owner directed and (2) unforeseen conditions. Riley (2005) reported an 87% decrease in average number of unforeseen or field initiated change orders on DB versus DBB projects and observed the average size of unforeseen change orders to be 86% smaller on DB projects. The overall cost growth due to DB change orders was found to be 71% lower than DBB, but more importantly a 98% decrease in cost growth due to unforseen change orders. Riley (2005) conculed DB reduces the frequency of field generated change orders.

A Construction Industry Institute (CII 2004) study consisted of a 617 project data subset taken from the Construction Industry Institue Benchmarking and Metrics database consisting of domestic USA and international projects where 210 (34%) were clasified as DB and 407 (66%) as DBB. The study found “when performance metrics were statistically different between DB and DBB projects the practices that had the most impact on DB project performance were different from the practices that had the most impact on DBB projects.” Owner DB projects tended to yield better performance results overall by outperforming DBB in cost, schedule, changes, rework, and practice use metrics. Whereas contractor DBB projects exibited statistically significant better schedule performance than DB projects. The other performance metrics had mixed results.

One of the potential disadvantages of the DB approach regards cost containment. Since a design and construction firm is hired before the actual design process begins, a firm cost cannot be established early in the life of a project. As for the DBB approach, the greatest potential disadvantage comes in the way of schedule because of the sequential nature of the project activities. “There has been little empirical evidence to date, however, that establishes quantifiable evidence of the superiority of one approach over the other” (CII 2004).

Ibbs (2003) conducted a study of 67 global projects taken from the Construction Industry Institute (CII) database. Most projects in the dataset were between $25 million and $75 million according to their total installed cost with the majority being large and complex. Forty five percent of the projects were DBB, 36% DB, and 19% other project delivery systems. Lump sum was used more often at 30% of all projects, cost plus fixed fee 12% utilization, and cost plus percentage of fee was employed on 15% of the projects. Ibbs (2003) defined cost growth as “the difference between the cost at the completion of the project and the original budget” (Ibbs, et al. 2003), and schedule growth as “the difference between the time used to complete the whole project and the estimated time to complete the project" (Ibbs, et al. 2003). This study analyzed the effects on labor productivity as a function of change in scheduled and cost, then analyzed by project delivery system.

Ibbs (2003) concluded "DB did not perform much better than DBB". Timesaving is a benefit of using DB however, the benefit of cost and productivity effects are not as pronounced by using regression analysis. The analysis shows that both delivery systems may work well depending on the expertise and experience of those administrating the project in design and construction.

2.5 Results of Prior Studies

Recently published studies find that overall DB out performs DBB based on various tests of project performance (CII 2004; Riley, et al. 2005; Hale, et al. 2009; Rosner, et al. 2009). However, these findings are not supported by all researchers (Ibbs, et al. 2003; Minchin, et al. 2013). Table 2 below summarizes findings from previous comparative studies.

Table 2 Findings of Previous Studies Conducted on BD and DBB

Researchers	System	Sample size	Project types	Project size	Major findings
Ibbs et al. (2003)	DB DBB	24 30	Buildings	$5 MM to $1 B	Cost growth for DB was 7.8% higher than that for DBB. Schedule growth for DB was 2.4% lower than that for DBB.
CII (2004)	DB DBB	210 407	CII Benchmarking and Metrics Data	$22.7 to $104.6M M	DB overall performed better with the exception of schedule performance for contractor submitted projects
Riley et al. (2005)	DBB DB	55 65	Mechanical Systems	$50K to >$300K	87% decrease in average number of unforeseen changes on DB projects. Unforeseen changes were 86% smaller on DB projects.
Hale et al. (2009)	DB DBB	38 39	U.S. Navy Bachelor Enlisted Quarters	$4.7MM to $37.5MM	DBB schedule growth approximately 2.5 times higher than DB. DB median cost growth approximately one third that of DBB.
Rosner et al. (2009)	DB DBB	278 557	U.S. Air Force Airfields, Maintenance Facilities & Dormitories	$6.9MM average $88MM max.	DB performed better in cost growth & change order rate. DBB exhibited better schedule performance. “Overall DB provided an advantage over DBB for MILCON projects”.
Minchin et al. (2013)	DB DBB	30 30	Florida Department of Transportation Highway Paving & Bridge Projects	$7MM and greater	DBB performed better in terms of cost. DB reported a slightly better duration performance.

Source: Adapted from (Hale, et al. 2009)

CHAPTER 3

RESEARCH METHODOLOGY

3.1 Introduction

This investigation compares the traditional Design-Bid-Build project delivery system to an alternative delivery system Design-Build and examines the relationship between project performance and the delivery system used to execute them to determine if one system out performs the other. A detailed study was conducted to compare the performance of two delivery systems by analyzing performance indicators through statistical methods to formulate a conclusion. The methodology used to achieve this objective is broken down into the following phases:

Phase I: Literature Review

Phase II: Data Collection & Preparation

Phase III: Data Analysis

3.2 Phase I: Literature Review

This phase of the investigation is to gain an in-depth knowledge of the Design-Bid-Build and Design-Build project delivery systems through a comprehensive study of the existing body of knowledge consisting of refereed journals, research papers, thesis, dissertations, and text books. Roles and responsibilities of project participants were studied to gain an understanding of their interactions; success indicators with their measurement, contract selection methods, as well as contract pricing methods were also studied.

3.3 Phase II: Data Collection and Preparation

Data collection is preparatory to analysis and consists of gathering information stored in various locations and formats. The data collected determines what analysis may be conducted to meet the research objective. Data was randomly collected from one of Saudi Arabia's largest project owners and consisted of 297 contracts. Five contracts were found to be extreme outliers statistically and were removed leaving the analytical dataset at 292 records. The information was compiled into one dataset for analysis with contracts distributed throughout the

Kingdom and considered only capital construction projects. The information collected includes; original contract value, number of contract changes, value of contract changes, planned start date, planned completion date, actual completion date, project delivery system, contract pricing method, contract selection method, industry type, contractor ownership, and 10 performance indicators.

The original contract value and value of contract changes was used to develop the cost performance output which is “viewed in terms of overall actual final cost versus the established project budget” (Anderson, et al. 2006; Ibbs, et al. 2003). The planned and actual schedule dates were used to develop schedule performance output defined as overall actual final duration versus planned project duration (Anderson, et al. 2006; Ibbs, et al. 2003). Additionally this study includes the project contract change order rate expressed as the number of contract change orders per million dollars of contract value (Rosner, Thal and West 2009)

For the purposes of this study a project delivery system is defined as DBB if the company performed: (1) either the design function only, (2) the construction function only, or (3) greater than 50% of either design or construction. Otherwise they will be categorized as DB (CII 2004).

“The general concept of project success remains ambiguously defined because of varying perception… Each project participant will have his or her own view of success ” (Chan, Scott and Lam 2002). For example; Ling “identified 59 potential factors affecting project performance” (Ling, et al. 2004) and the CII (2006) study “defined over 180 leading indicators as fundamental project characteristics and / or events that reflect or predict project health”.

“Traditionally, success is defined as the degree to which project goals and expectations are met…Project success is the goal, and the objectives of budget, schedule, and quality are the three normally accepted criteria to achieve the goal” (Chan, Scott and Lam 2002). Chan (2002) describe project cost and time outputs as objective or tangable measures. Stevens (1996) describes cost and time as “hard” measurements. “…quality, technical performance, satisfaction, productivity, and environmental stability” are described as subjective measures or intangable by Chan (2002) and “soft measurements” by Stevens (1996).

For this thesis the 10 subjective indicators, are: (1) management / administration, (2) equipment / facilities, (3) subcontracting, (4) planning / scheduling, (5) quality program, (6) technical competence / workmanship, (7) material procurement, (8) cost control (9) safety, and (10) loss prevention. With three objective indicators being (1) cost growth, (2) schedule growth, and (3) change order rate.

Information on the subjective indicators is recorded by the Owner's project management team in the form of a questionnaire (see Appendix D). The Owner uses this data to measure the health of the project during execution as well as judge the contractor for future work. The evaluation cycle is typically on a 6 month interval during the project performance period with a final overall evaluation at project completion. The data collected at project completion is the subject of this study. For scores of average or above (1 through 3) no action is taken however, if a contractor is evaluated as either 4 or 5 (below average) a counseling session is held to put the contractor on formal contractual notice of areas for improvement or face further corrective action up to and including termination.

3.4 Phase III: Data Analysis

This phase describes the method by which data collected in Phase II is analyzed, coupled with the literature review, leading to meaningful conclusions. Inferences between the two independent project delivery systems DB and DBB were investigated by first dividing the overall data into 5 categories consisting of (1) base contract cost, (2) pricing method, (3) contract selection method, (4) industry group, and (5) company ownership. Secondly; the 13 performance indicators mentioned above will be tested by applying Student's t test by category through use of Minitab 16® and Sigma XL® statistical software.

Student's t Test is a commonly used statistical technique for hypothesis testing based on the differences between sample means. The t test compares two mean (average) values and determines a probability expressed as (p) to judge if two sample populations are the same or not also referred to as a statistical significance test. The outcome of these tests is to accept or reject a null hypothesis stated as H_0 for this study. The null hypothesis generally states that there is no difference between the two values (hence null) and any differing results are purely due to random, non-systematic errors. The alternative hypothesis (H_1) states the opposite. Statistical significance tests provide results within a predefined confidence level expressed as a percentage. Commonly used confidence levels are 90%, 95% and 99%. A Type 1 error is defined as erroneously rejecting H_0 whereas erroneously failing to reject (accepting) H_0 is a Type 2 error. By decreasing the confidence level to 90%, rejection of H_0 becomes easier which increases the probability of Type 1 errors. Conversely by increasing the confidence level to 99% making rejection of H_0 more difficult the probability of a Type 2 error increases. Therefore a confidence level of 95% is generally considered a compromise between the two risks and is widely accepted in the field of construction research.

CHAPTER 4

PROJECT CHARACTERISTICS and DATASET DESCRIPTION

4.1 Introduction

This study compares the performance of two project delivery systems (DB and DBB) by analyzing 13 indicators through statistical methods in order to formulate a conclusion. The overall dataset was divided into 5 subsets by: (1) cost category, (2) pricing method, (3) contract selection method, (4) industry group, and (5) company ownership. The performance indicators were then analyzed by subset through calculating the mean for each. The null hypothesis was then tested by applying Student's t test to determine if the difference between the mean values were statistically significant.

4.2 Data Sample Characteristics by Category

Information from several databases was compiled into one dataset for analysis. This dataset consists of 292 randomly selected contracts for capital construction projects having locations throughout the Kingdom and includes information on base contract value, pricing method, selection method, industry group, company ownership, as well as 13 performance indicators. Some contract payment provisions were reported in Saudi Arabian Riyals, if so the values were converted into United States Dollars (USD), using the Saudi government established static currency exchange rate of SAR3.75 / USD.

Based on the decision rule developed by the Construction Industry Institute (CII 2004), projects were categorized as DBB if the company performed: (1) either the design function only, (2) the construction function only, or (3) greater than 50% of either design or construction. Otherwise they were categorized as DB. Of the 292 projects studied, 88 projects or 30% were categorized as DB for which the contractor performed greater than 50% of the design and construction effort, with the remaining 204 projects or 70% defined as DBB.

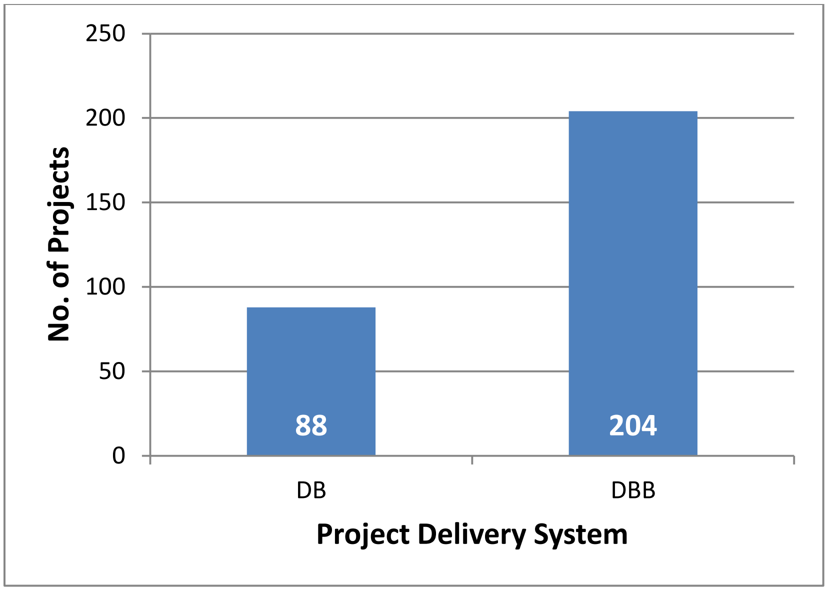


Figure 5 Projects by Delivery System

Table 3 - Average Base Contract Value ($MM)

Metric	DB	DBB
All Projects	79.5	16.1
Lump Sum	80.1	13.7
Unit Rate	52.1	68.7
Pre-qualified	15.0	13.7
Sole Source	29.5	27.4
Open-Low Bid Wins	179.3	35.4
Industrial	101.5	19.0
Commercial	16.3	9.4
Saudi	13.8	5.7
Multi-National	116.4	56.8

The average base contract value excluding change orders expressed in millions of dollars are reported in Table 3 above. Overall DB projects are 5 times larger than DBB along with Open-Low Bid Wins and Industrial projects. DB lump sum projects are 6 times larger than DBB which may reflect the owner's risk appetite on larger projects. Or perhaps the owner is attempting to leverage the fast track trait of DB by overlapping design and construction functions to shorten the overall performance period. There is virtually no difference in size between DB and DBB unit rate, pre-qualified, and sole source projects, although unit rate DBB is slightly larger than DB. While DB commercial, Saudi and multi-national projects are twice the size of DBB. DB projects executed by multi-national construction companies are 8 times larger than Saudi owned construction company projects however, DBB projects executed by multi-national companies are 10 times larger than their Saudi counterparts.

The data is grouped into 5 categories consisting of:

1. Projects by cost category
2. Projects by pricing method
3. Projects by selection method
4. Projects by industry group
5. Projects by company ownership

The data is analyzed by 13 performance indicators within each of the 5 categories as shown below:

1. Cost growth
2. Change rate
3. Schedule growth
4. Management & administration
5. Equipment / facilities
6. Subcontracting
7. Planning & scheduling
8. Quality
9. Workmanship
10. Material procurement
11. Cost control
12. Safety
13. Loss prevention

4.2.1 Projects by Cost Categories

Figure 6 depicts the breakdown of projects by cost category. Cost categories are reported in millions (MM) of United States Dollars (USD) based on the original contract value without cost increases due to change orders and are divided into less than $15MM, between 15 and $50MM and greater than $50MM ranges.

The DBB project delivery system dominated the <$15MM range being used nearly 5 times more frequently than DBB with 160 (55%) projects as compared to the DB project delivery system with only 33 projects (11%). Among the $15-$50MM and >$50MM ranges the difference between the delivery systems are less dramatic.

For the $15-50MM range the difference between the BDD and DB delivery systems is 2% with DBB utilization being 23 projects (8%) and DB being used on 17 (6%) of the projects.

DB projects were employed at almost twice the rate of the >$50MM range with 38 projects (13%) and 21 (7%) of projects used DBB.

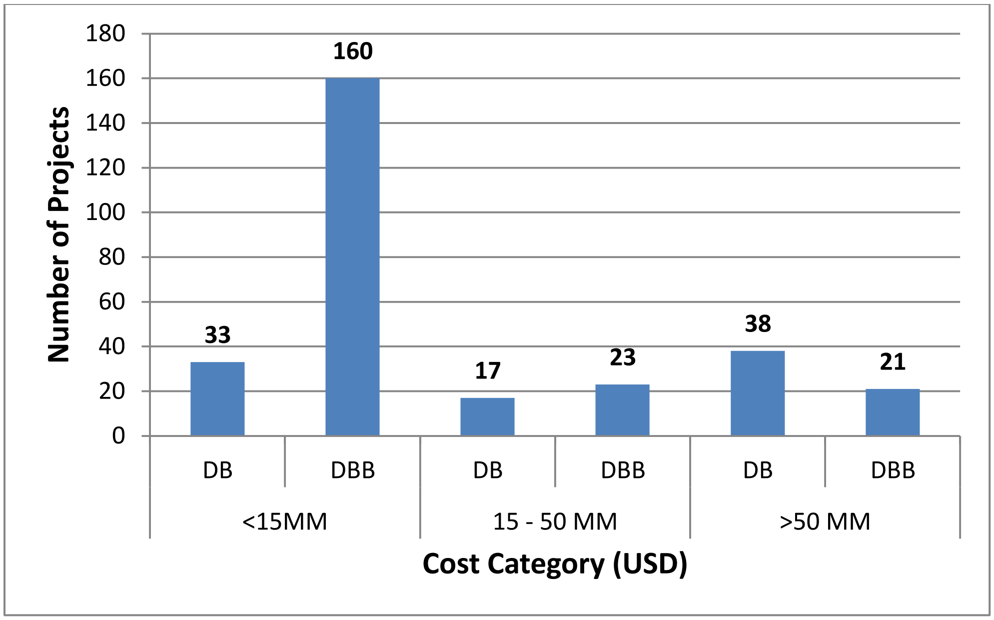


Figure 6 Projects by Cost Category

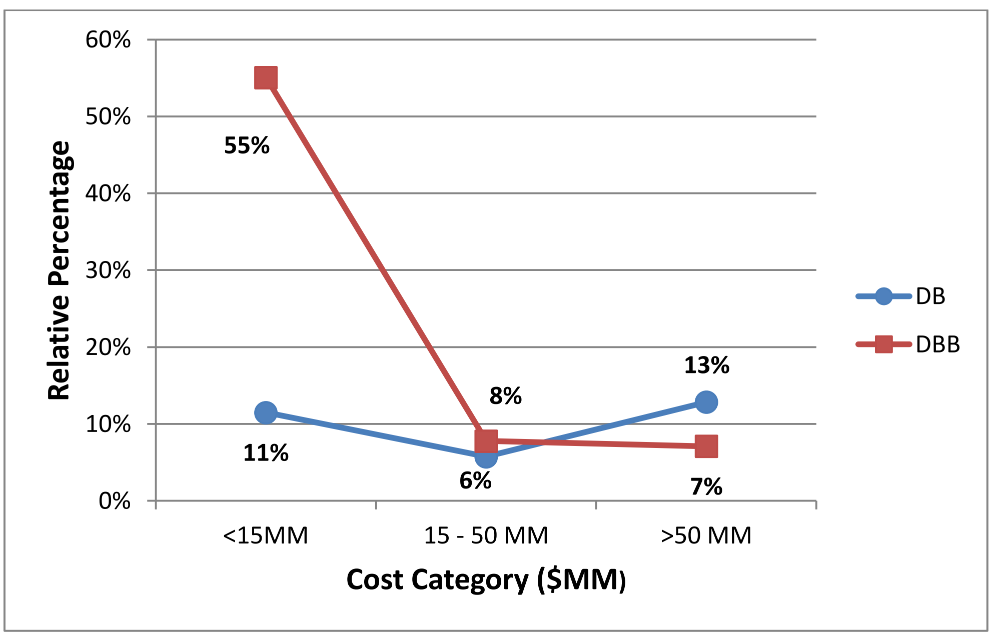


Figure 7 Relative Percentages of Projects by Cost Category

4.2.2 Projects by Pricing Method

Two major pricing methods employed were lump sum and unit rate. Among the total projects lump sum DBB overshadowed the other groups, accounting for 67% (195) of all projects leaving 29% (86) for lump sum DB. The unit rate method accounted for 1% (2) and 3% (9) respectively for DB and DBB.

4.2.2.1 Lump Sum

The combined DB and DBB lump sum projects equal 281 of the total 292 or 96% of the projects with base contract values ranging between $93K and $557MM; the mean value is $34MM; and median of $5MM. Lump sum DBB is two times more likely to be used than lump sum DB. The average base contract value for the lump sum DB projects is $80.1MM and $13.7MM for DBB.

4.2.2.2 Unit Rate

There are 11 combined DB and DBB unit rate projects or 4% of the total, having a base contract values ranging between $54K and $332MM; the mean value is 65MM and the median is $5MM. The average base contract value for unit rate DB projects is $52.1MM and $68.7MM for DBB.

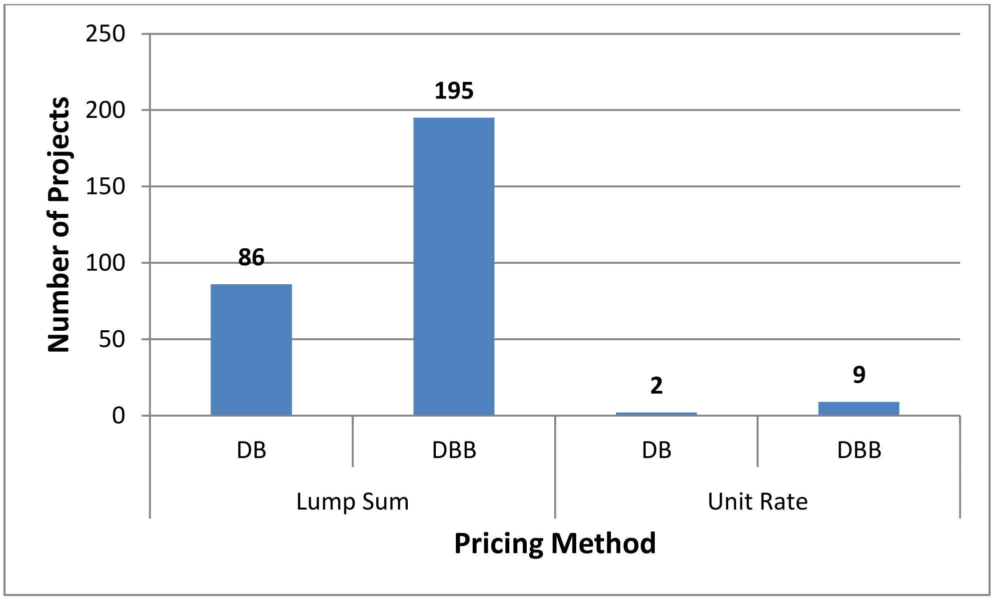


Figure 8 Projects by Pricing Method

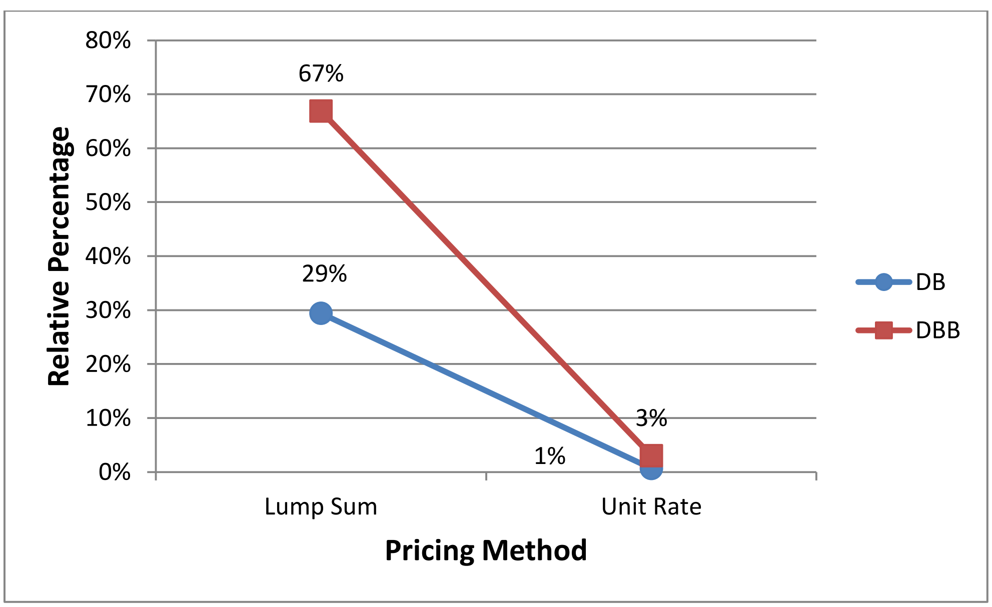


Figure 9 Relative Percentages by Pricing Method

4.2.3 Projects by Selection Method

The dataset include three selection methods being; pre-qualified bidder, open solicitation, and sole source. The pre-qualified bidder method consists of a list of prospective bidders pre-qualified in advance of the bidding process. Only these pre-qualified bidders are invited to offer competitive price proposals. The open solicitation method employees a pre-qualification questionnaire distributed with the bid documents to be submitted as part of the contractor's competitive price proposal. The third method is sole source which is a non-competitive bid solicitation limited to a single contractor offering a proposal in response to a bid solicitation.

4.2.3.1 Pre-qualified Bidder

Pre-qualified bidding is a method of competitive contract procurement in which only a limited number of contractors considered technically and financially qualified in advance to perform the proposed work are invited to offer bid proposals. The pre-qualification process allows the Owner two opportunities to evaluate the contractor's qualifications, once during bid slate development and again during the bid review process. The pre-qualified bidder method was used predominantly to select contractors by awarding 257 out of 292 projects by this method which comprises 88% of the overall dataset. Of the 257 contracts 77 (26%) were DB with the remaining 180 (62%) being DBB indicating the owner overwhelmingly favors awarding contracts by pre-qualified DBB. The base contract size for this subcategory combining DB and DBB are between $54K and $557MM with an average of $32MM and median of $5MM.

4.2.3.2 Open Solicitation

The open solicitation contract procurement is a competitive method in which all financially and technically qualified contractors may submit a bid for a publically advertised contract. The owner has only one chance to evaluate the contractor's qualifications during the bid review process. Twenty six or 9% of the contracts were selected by the open solicitation. Of these 26 contracts 6 (2%) were DB and 20 (7%) DBB this subset represents a small portion of the overall number of projects the lowest base contract value is $93K and the maximum is $406MM with the mean being $67MM and median being $9MM.

4.2.3.3 Sole Source

The sole source or sometimes referred to as a "no-bid contract" procurement method consists of the non-competitive selection of a contractor based on past performance, technical qualifications, and the owner's relationship established through previous projects. The least favored selection method was sole source with only 3% or 9 contracts awarded by this method. Of the 9 contracts the difference was almost even with 2% (5) being DB and 1% (4) DBB. Even though sole source is the least favored selection method the median base contract value is $27MM or 3 times greater than open solicitation and over 5 time greater than the prequalified method. The minimum contract was $659K and largest contract value was $80MM.

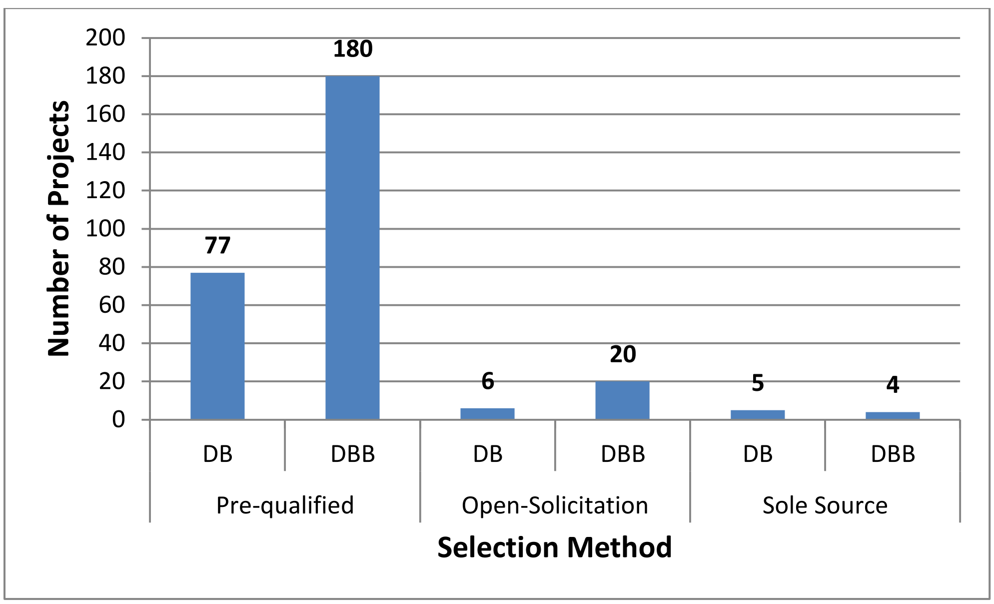


Figure 10 Projects by Selection Method

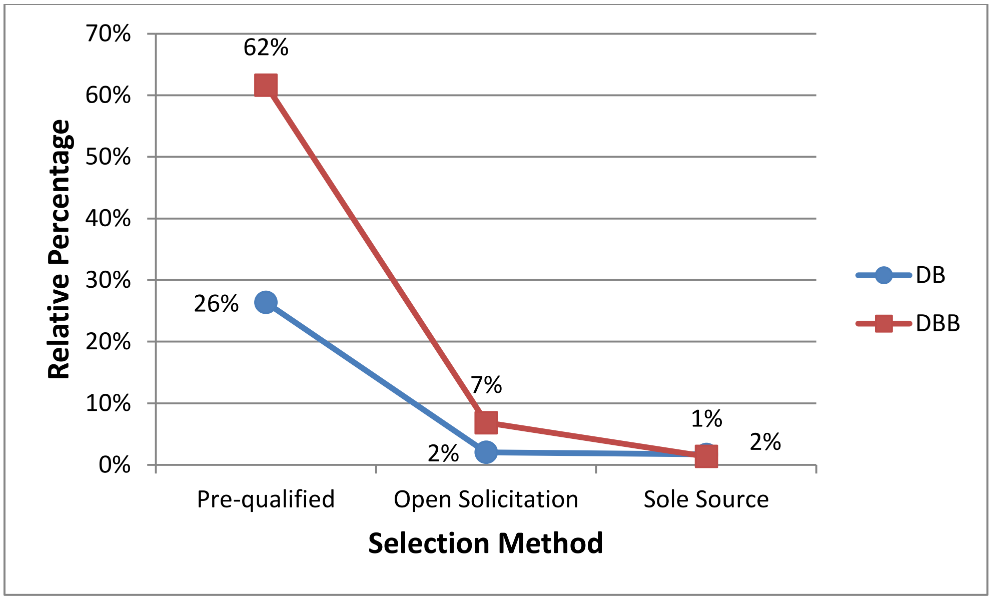


Figure 11 Relative Percentages by Selection Method

4.2.4 Projects by Industry Type

The projects were segregated into two groups, industrial and commercial which follow a similar pattern in both cases with DBB being used more frequently. Combining the two groups (industrial and commercial) DB was used 88 times while DBB was used 204 times.

4.2.4.1 Industrial

Grouped together as Industrial type projects are petro-chemical and petroleum refining facilities, pipelines, industrial storage facilities, treatment plants, industrial fire water systems, pump stations, offshore structures, desalinization plants, co-generation plants, and waste water treatment plants.

The total count for the Industrial Group is 207. DBB is applied on industrial projects at twice the rate of DB. Sixty five contracts out of 207 are DB and 142 are DBB. $557MM and $54K are the maximum and minimum contract values for this subset having a mean and median of $45MM and $8MM respectively.

4.2.4.2 Commercial

The Commercial data subset consists primarily of public work projects with some industrial support facilities including residential housing blocks, elementary and secondary schools, roadways, research and development laboratories, office buildings, communication facilities, fire stations, craftsmen training, and test centers.

Among the 85 commercial projects DBB was used 3 times more often than DB or 23 projects being DB and 62 projects being DBB. The minimum base contract awarded was $383K and $210MM was the maximum. The mean and median respectively were $11MM and $4MM.

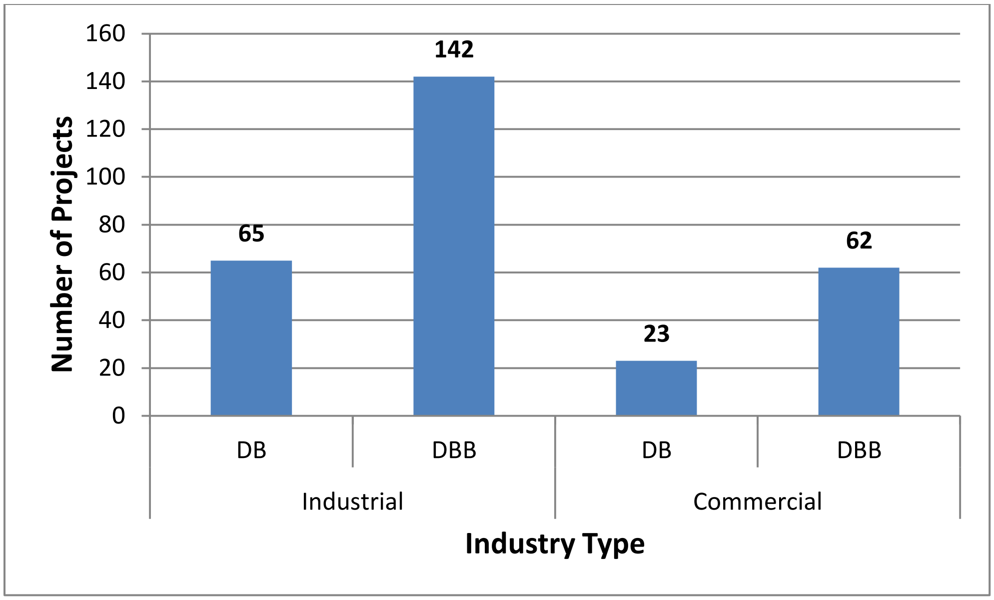


Figure 12 Projects by Industry Type

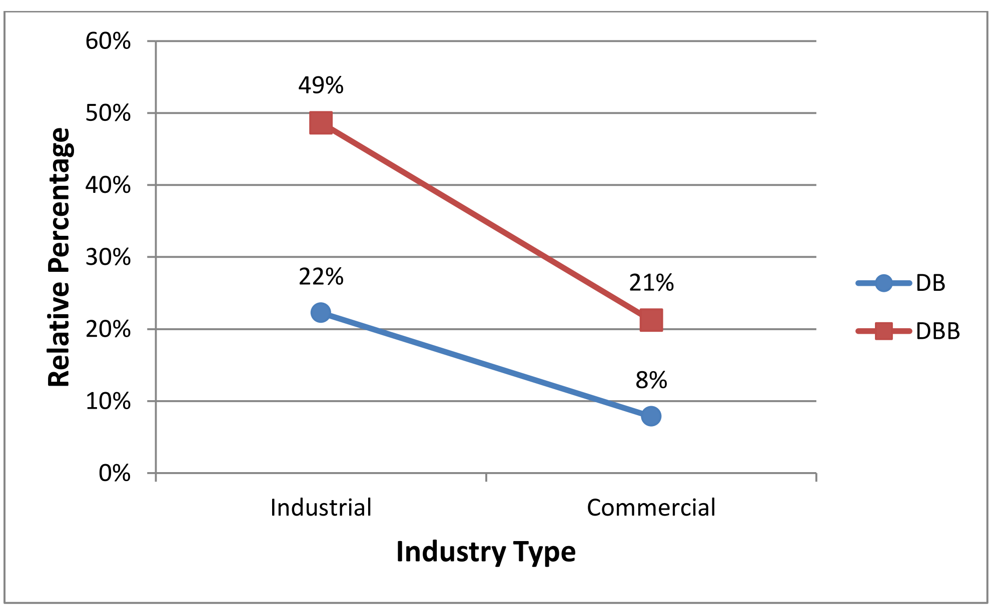


Figure 13 Relative Percentages by Industry Type

4.2.5 Projects by Company Ownership

Company ownership is defined by nationality. In order for a company to be considered Saudi Arabian it must be 100% owned by a Saudi national citizen/s otherwise it is classified as multi-national. This data sub-set consists of 193 (66%) projects identified as Saudi Arabian and 99 (34%) as multi-national.

4.2.5.1 Saudi Arabian Ownership

One hundred sixty two (55%) of the awarded projects are Saudi Arabian owned companies delivered by the DBB system as compared to 31 or 11% DB. The difference between the two delivery systems is 44%. The contract sizes are between \$54K and \$102MM with a median value of \$2.5MM and average contract size \$7MM.

4.2.5.2 Multi-national

The difference between Multi-national delivery systems is nearly equally divided between DB and DBB, with 57 (20%) and 42 (14%) of the projects being DB and DBB respectively equating to only a 6% difference between them. Nine hundred ninety thousand dollars ($990K) and $557MM is the contract range with the average size being $91MM and the median $55MM.

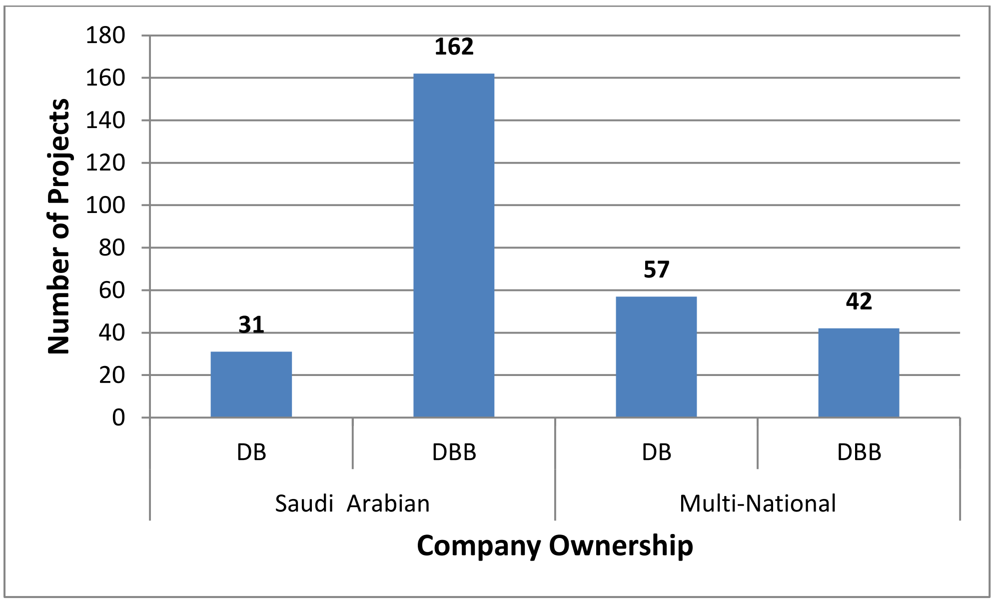


Figure 14 Projects by Company Ownership

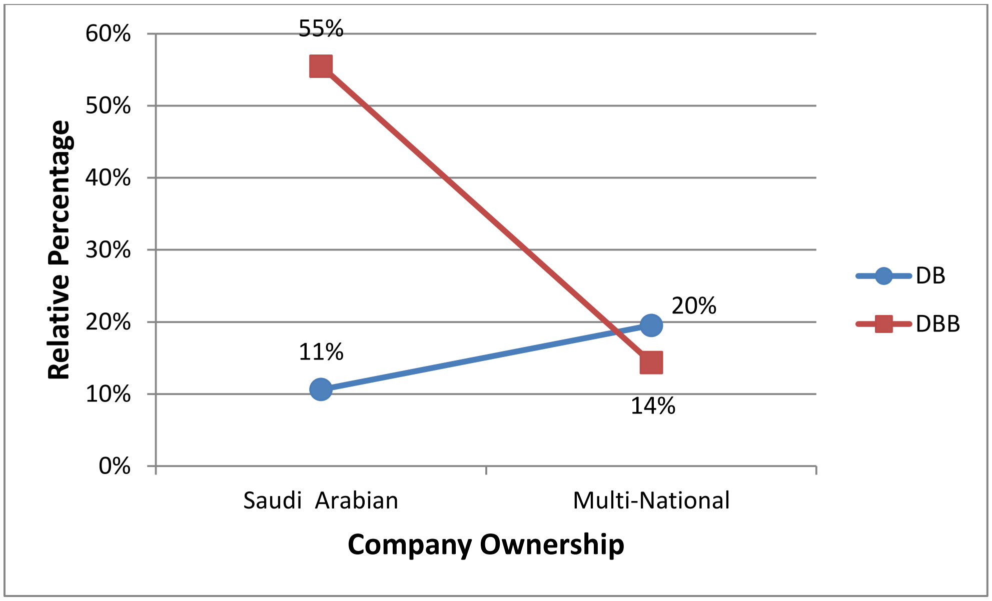


Figure 15 Relative Percentages by Company Ownership

4.2.6 Performance Indicators

A review of the existing body of knowledge identified various performance factors used by previous researchers and project practitioners. This study encompasses some of those factors and considers others as well.

The project delivery systems DB and DBB were compared against each other grouped in the 5 categories described above by a series of 13 performance factors consisting of; (1) cost growth, (2) schedule growth, (3) number of contract change orders per contract, (4) subcontract management and administration, (5) equipment and facilities, (6) subcontracting, (7) planning and scheduling, (8) quality, (9) workmanship, (10) material procurement, (11) cost control, (12) safety, and (13) loss prevention.

The 10 soft or subjective performance factors, items 4 through 13 above, were evaluated by the field project execution team at predetermined intervals during the contract period, including a final overall evaluation at project closeout. The scores studied in this thesis are the final overall evaluations at project completion. A scale of 1 to 5 was used to evaluate the contractor's performance 1-outstanding, 2-above average, 3-average, 4-below average, and 5-unsatisfactory. The data collection questionnaire may be found in Appendix D.

4.2.6.1 Cost Growth

Cost growth may be defined as the sum of approved contract change order values divided by the original contract value expressed as a percentage. "Contract modifications originate from many different sources. They can be indications of design or construction errors or environmental and unforeseen site conditions. In some cases, they may indicate additional benefits added to the project" (Rosner, et al 2009). A limitation of this study is the root cause of change orders was not identified in the Owner's database therefore; the assumption is all changes were associated with a negative cause.

$$Cost\ Growth = \left(\frac{\sum Approved\ Contract\ Change\ Orders}{Original\ Contract\ Value}\right) X\ 100 \qquad \text{Equation 1}$$

This sample consists of 88 DB and 204 DBB contracts for a total of 292 data points. The cost growth ranged between 0% and 40.0% for DB with an average 4.9% and median of 1.8%. Similarly for DBB the smallest contact change is 0% with the largest cost growth of 45.3% and median of 4.2% and average of 7.0%. Figure 16 indicates a data distribution with a single long tail. The left skew is driven by 38 contracts or 13% of the total dataset having a 0% cost growth or in other words there were no change orders written against the base contract. Five of these contracts belong to DB with the remaining 33 DBB.

Table 4 -Descriptive Statistics – Cost Growth

Descriptive Statistics	Project Delivery System = DBB	Project Delivery System = DB
Count	204	88
Mean	7.0%	4.9%
Stdev	8.4%	7.5%
Range	45.3%	40.0%
Minimum	0.0%	0.0%
25th Percentile (Q1)	0.6%	0.4%
50th Percentile (Median)	4.2%	1.8%
75th Percentile (Q3)	10.0%	6.8%
Maximum	45.3%	40.0%

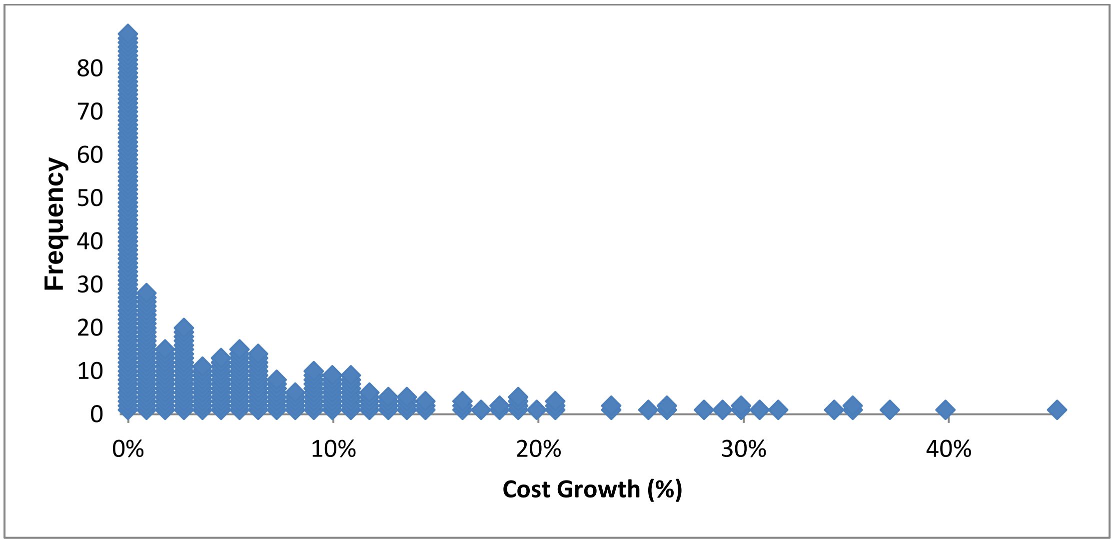


Figure 16 Dot Plot - Cost Growth (%) Combined PDS Dataset

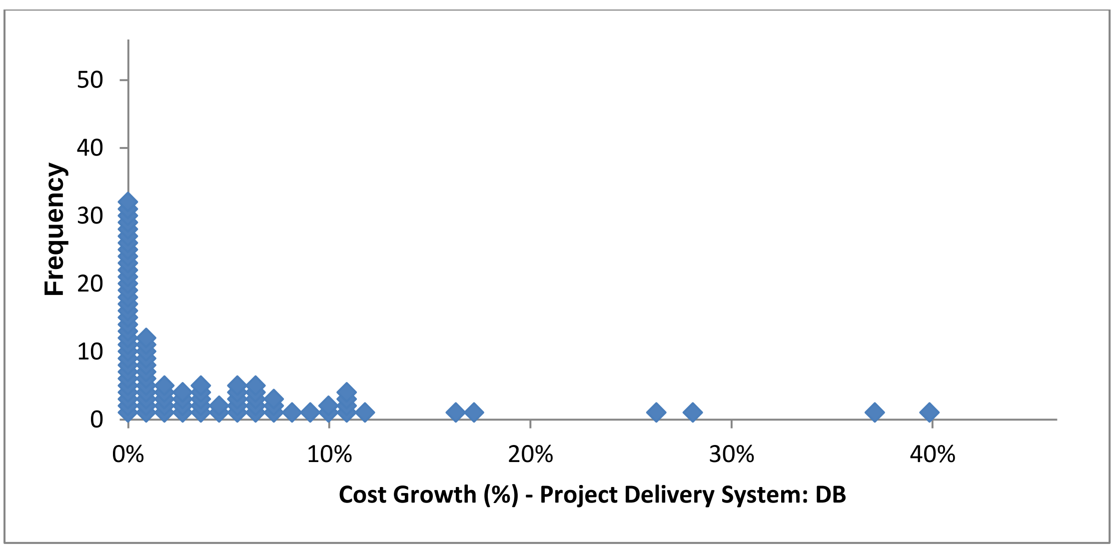


Figure 17 Dot Plot - Cost Growth (%) - DB

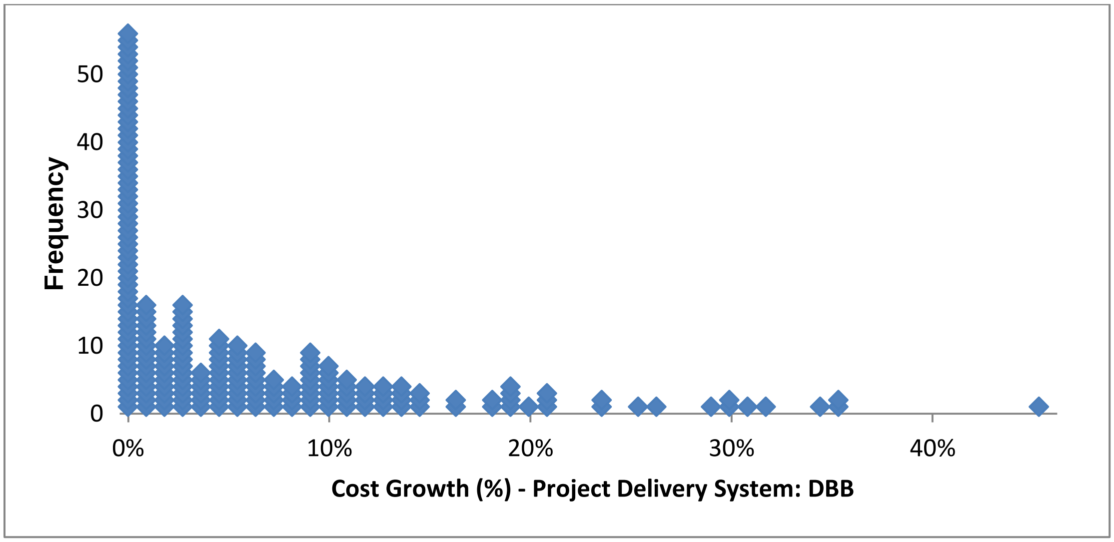


Figure 18 Dot Plot - Cost Growth (%) - DBB

4.2.6.2 Contract Change Order Rate

In construction, project change is inevitable whether owner directed or field generated. “Owner-generated change orders are issued when an adjustment to the project scope, design, or detailing is requested by the owner, and a change to the original contract agreement is required. “Field-generated change orders arise when problems and conflicts are detected in the field that requires a re-design or reconfiguration of the design” (Riley, et al. 2005; Rosner, et al. 2009)

The change order rate, or sometimes referred to as modifications per million dollars, performance factor is defined in this study by the sum of approved contract change orders (count) divided by the total contract value expressed in million dollars (equation 2). Rosner (2009) identified this metrix as an “indirect measure of how many problems the project experienced *used* to quantitatively compare the typically subjective quality performance of the DB and traditional DBB delivery methods”.

$$Change\ Order\ Rate = \frac{\sum Approved\ Contract\ Change\ Order\ Quantity}{\left(\frac{Base\ Contract\ Value}{1MM}\right)} \qquad \text{Equation 2}$$

This sample consists of 88 DB and 204 DBB projects for a total of 292 data points. The number of change orders range between 0 and 113 for DB. Similarly for DBB the least number of change orders written against a single contract is 0 and the most is 133. The average change order rate for DB is 0.7 changes / million with a median of 0.4 changes / million, a minimum of 0 and maximum of 4.0. As for DBB the average change order rate is 1.9 changes / million dollars with a median of 1.1 changes / million dollars, the minimum is 0 and a maximum of 31.1 changes / million dollars.

Table 5 - Descriptive Statistics – Change Order Rate

Descriptive Statistics	Project Delivery System = DBB	Project Delivery System = DB
Count	204	88
Mean	1.9305	0.6965
Stdev	3.1048	0.8342
Range	31.0651	3.9989
Minimum	0.0000	0.0000
25th Percentile (Q1)	0.2193	0.0797
50th Percentile (Median)	1.0740	0.4300
75th Percentile (Q3)	2.3795	0.9650
Maximum	31.0651	3.9989

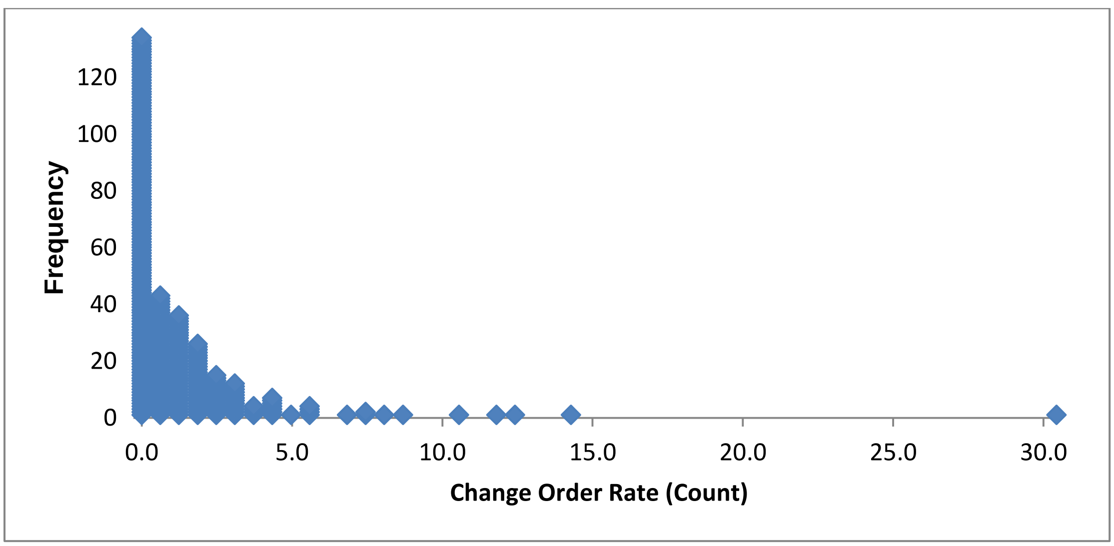


Figure 19 Dot Plot - Change Order Rate – Combined PDS Dataset

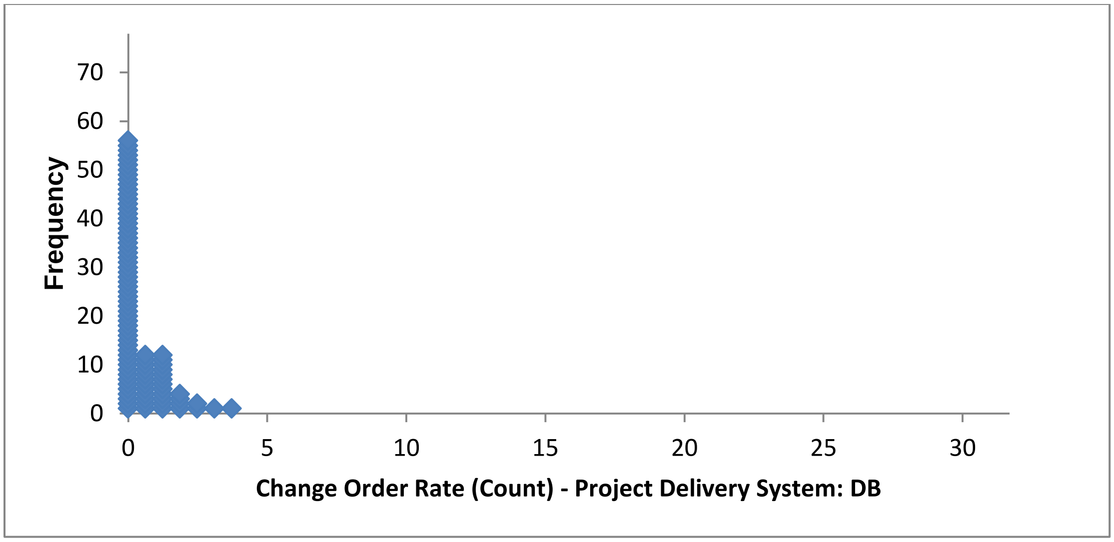


Figure 20 Dot Plot - Change Order Rate - Project Delivery System DB

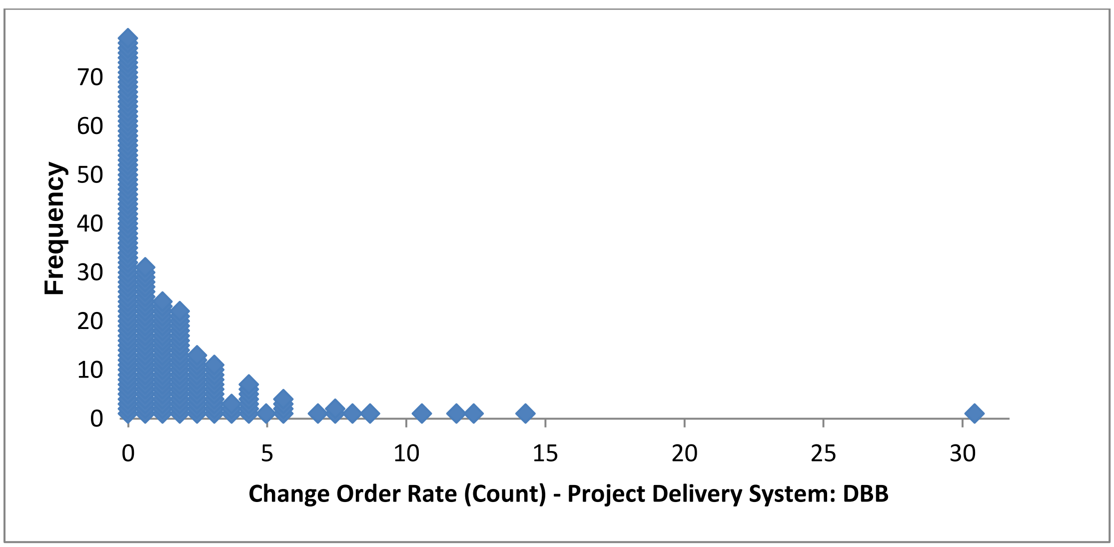


Figure 21 Dot Plot - Change Order Rate - Project Delivery System DBB

4.2.6.3 Schedule Growth

Schedule growth is the elapsed time between the project planned completion and actual completion dates divided by the original contract duration reported in percentage with negative values indicating an early project completion.

$$Schedule\ Growth = \left(\frac{Actual\ Completion - Planned\ Completion}{Original\ Contract\ Duration}\right) X\ 100 \qquad \text{Equation 3}$$

This sample consists of 272 total data points, broken down into 78 DB and 194 DBB. DB experienced a minimum schedule growth of -44% (under run) and a maximum of 361% with a mean 73% of and median 50%, contrasted with DBB which had a minimum schedule growth of -76%, maximum 377%, median 47% and an average of 68%. The difference between the two delivery systems is 52% mean, 53% minimum, 51% median. The maximum schedule growth difference is 16% lower for DB with 84% of the projects studied experiencing schedule delay.

Table 6 - Descriptive Statistics – Schedule Growth

Descriptive Statistics	Project Delivery System = DBB	Project Delivery System = DB
Count	194	78
Mean	67.5%	72.9%
Stdev	82.6%	70.6%
Range	453.4%	405.3%
Minimum	-76.4%	-43.9%
25th Percentile (Q1)	4.4%	19.9%
50th Percentile (Median)	47.1%	49.5%
75th Percentile (Q3)	111.8%	108.4%
Maximum	376.9%	361.3%

Compared to other economies Hegazy (2008) reports:

> Construction delays are common in projects around the world. In the United Kingdom, a 2001 report by the National Audit Office, entitled "Modernizing Construction," revealed that 70% of the projects undertaken by government departments and agencies were delivered late. In India, a study conducted by the Infrastructure and Project Monitoring Division of the Ministry of Statistics and Programme Implementation in 2004 reported that of 646 central sector projects, costing about $50 trillion U.S. dollars, approximately 40% were behind schedule, with delays ranging from 1 to 252 months. In the booming United Arab Emirates (UAE), where construction contributes 14% to the gross domestic product (GDP), a study revealed that 50% of construction projects encounter delays (Hegazy and Menesi 2008).

The data distribution for schedule growth is as follows:

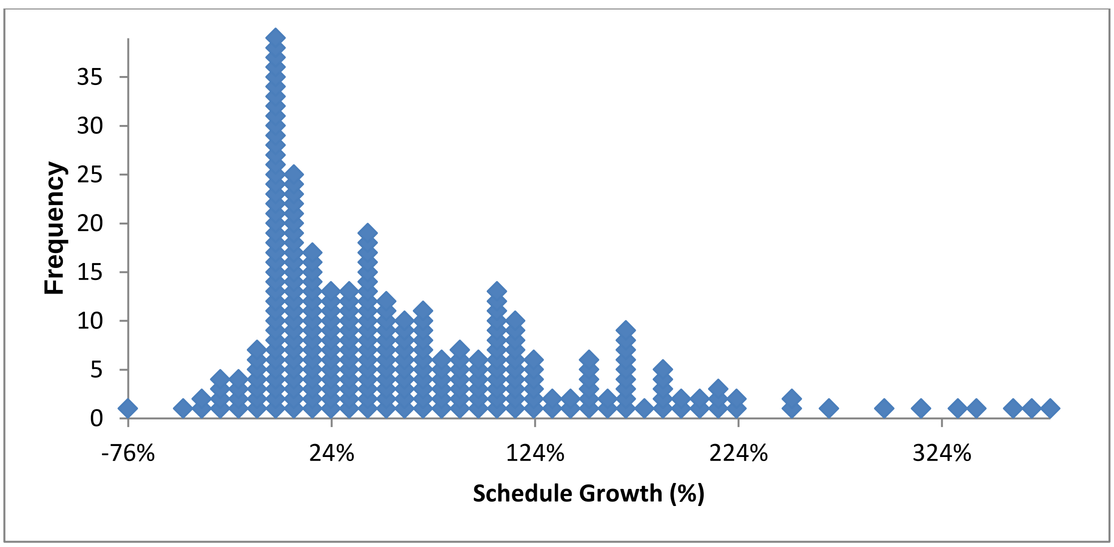


Figure 22 Dot Plot - Schedule Growth (%) Combined PDS

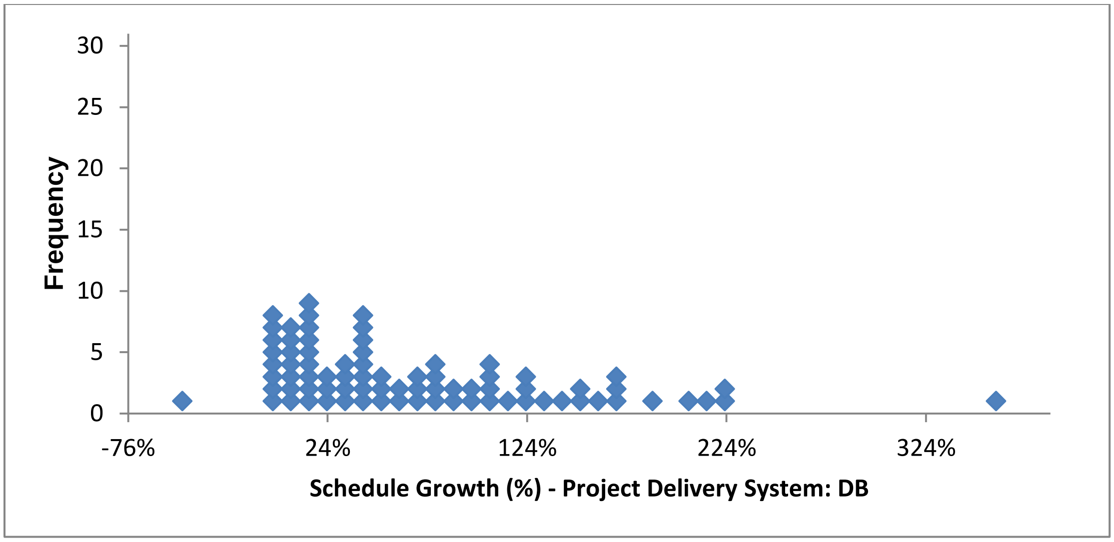


Figure 23 Dot Plot - Schedule Growth (%) - DB

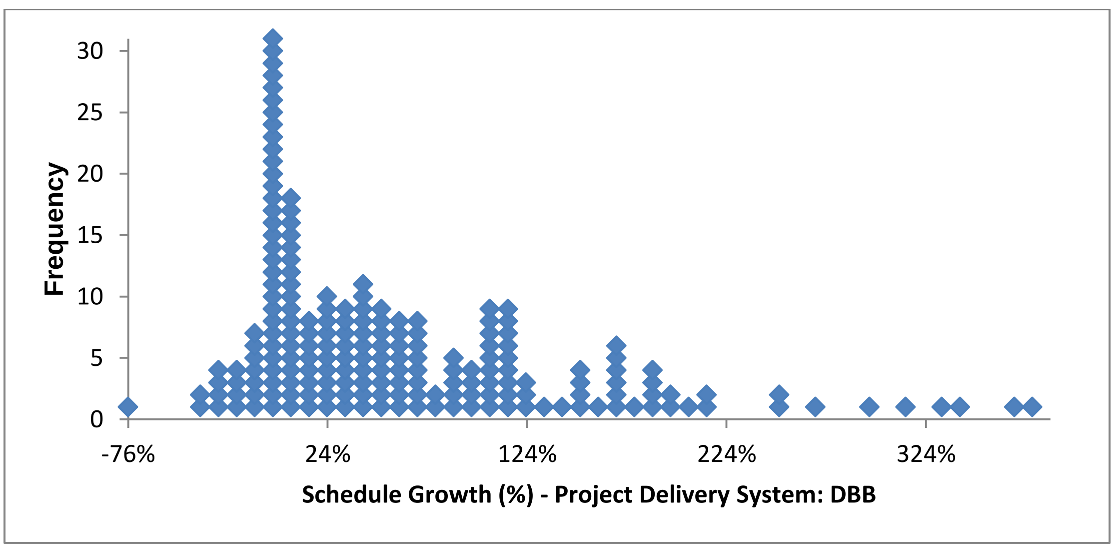


Figure 24 Dot Plot - Schedule Growth (%) - DBB

4.2.6.4 Management & Administration

This matrix evaluates the contractor's overall ability to manage and administer their prime contract with the owner. Major factors for evaluation are an acceptable organization chart, staffing plan with key personnel identified, regular open communication with the owner, team work, permits, licenses, permissions are secured timely. The total number of questionnaire responses is 175, with 27 DB (15%) and 148 (85%) for DBB. The data distribution for the management and administration performance factor is illustrated in the following dot plots. The combined DB and DBB data set is performance ratings are broken down as 4 outstanding, 77 above average, 79 average, 13 below average, and 2 unsatisfactory. Lower scores represent better performance.

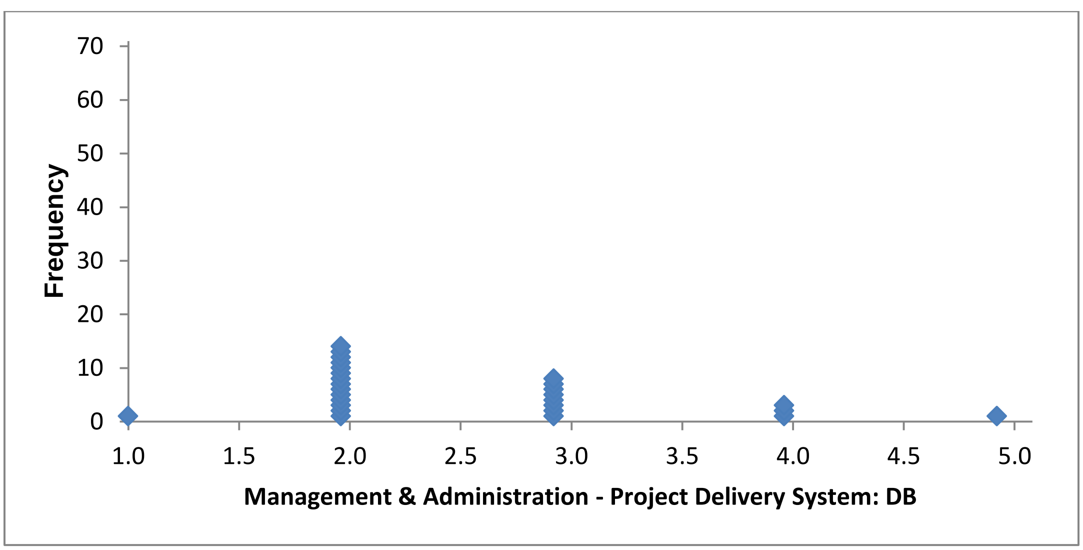


Figure 25 Dot Plot - Management & Administration - DB

The distribution for design-build projects begins with 1 project rated as outstanding, 14 above average, 8 average, 3 below average and concludes with 1 unsatisfactory rating.

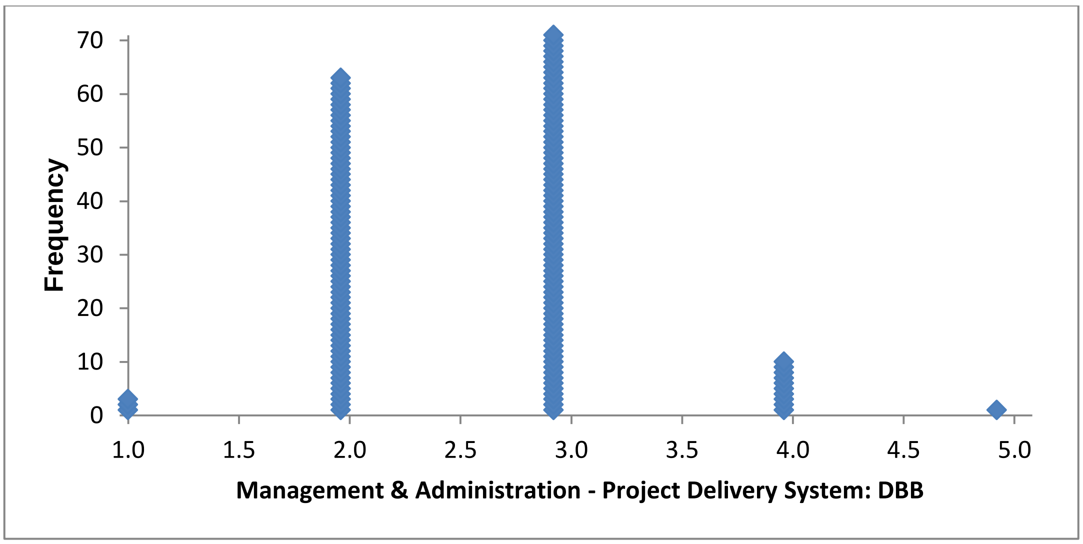


Figure 26 Dot Plot - Management & Administration - DBB

The data is distributed for design-bid-build projects is 3 outstanding, 63 above average, 71 average, 10 below average, and 1 unsatisfactory performance.

4.2.6.5 Equipment / Facilities

The evaluation criteria for this matrix include the contractor's construction personnel camp and field office facilities are in compliance with the contract requirements. The contractor's construction equipment is available for use, fit for purpose, and the equipment operators hold the correct certifications and / or licenses. Of the 172 questionnaire responses 28 (16%) were for DB the remaining 144 (84%) for DBB. Combined, the data is broken down into 12 outstanding, 67 above average, 86 average, 6 below average, and 1 unsatisfactory performance rating. Lower scores represent better performance.

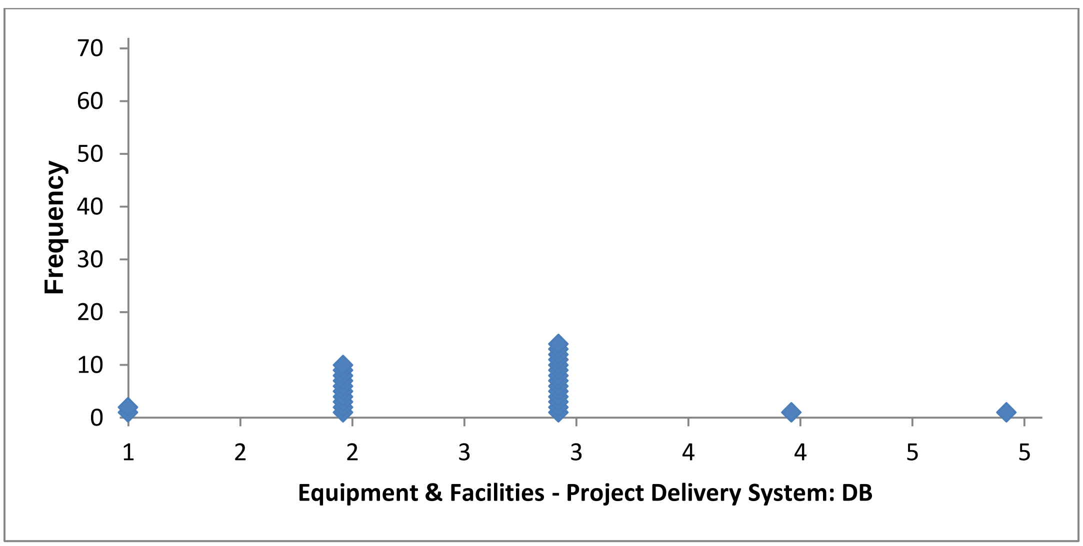


Figure 27 Dot Plot - Equipment and Facilities - DB

The sample size for DB is consists of 2 outstanding, 10 above average, 14 average, 1 below average, and 1 unsatisfactory rating.

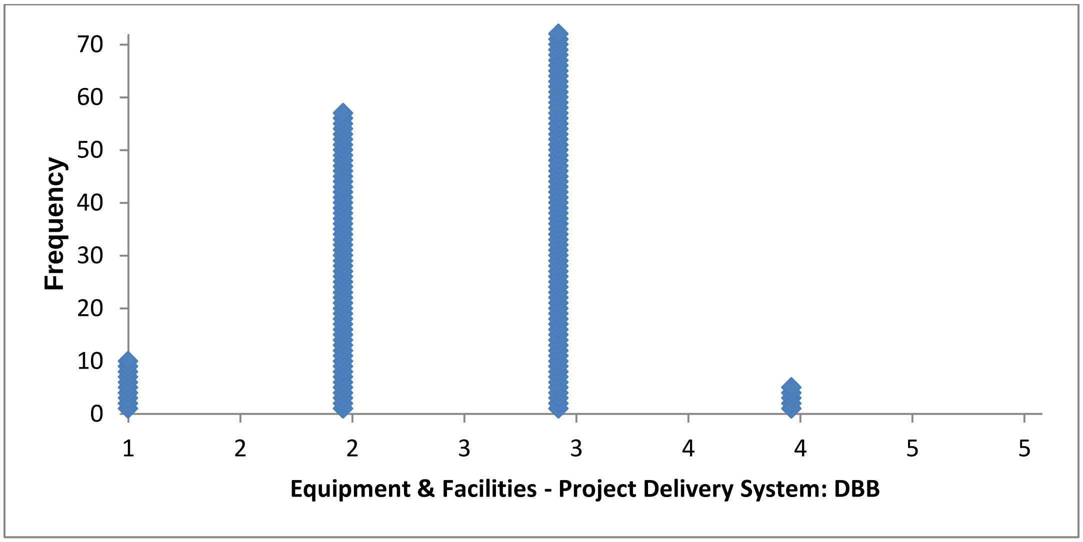


Figure 28 Dot Plot - Equipment and Facilities - DBB

The DBB sample size is 10 outstanding, 57 above average, 72 average, 5 below average and no unsatisfactory ratings.

4.2.6.6 Subcontracting

The contractor is evaluated by the completeness of their subcontracting plan and how the plan is managed. Criteria include completeness of the sub-tier subcontractor list, mobilization to support the construction schedule, familiarity with the owner’s standards, specifications, and procedures, as well as sub-tier subcontractor’s efficiency and knowledge of their specialty. The Subcontracting dataset contains 111 responses expressed by 22% (24) being DB and 78% (87) as DBB. Of these 111 responses 3 are rated outstanding, 32 above average, 69 average, 5 below average, and 2 unsatisfactory. Lower scores represent better performance.

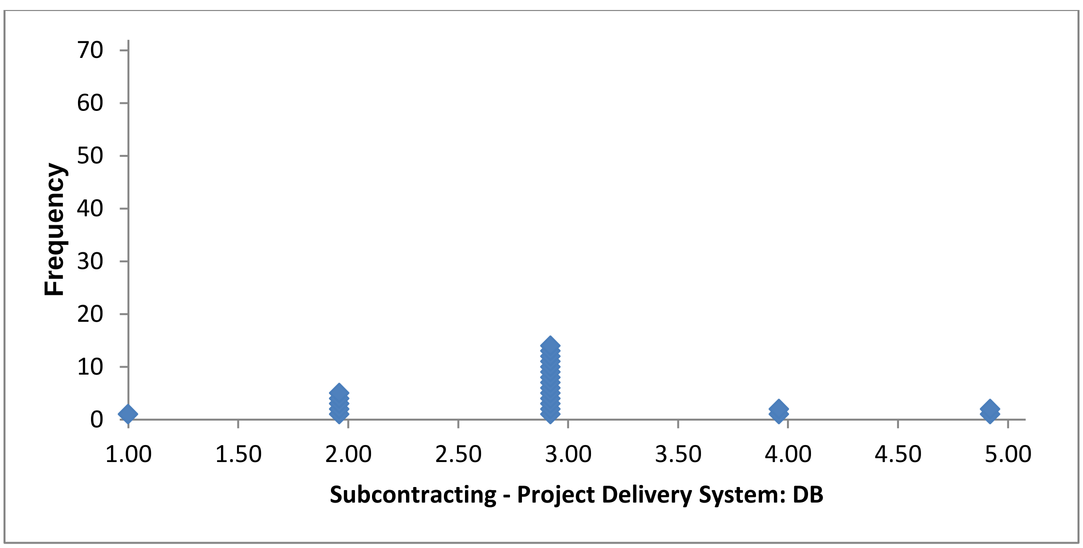


Figure 29 Dot Plot - Subcontracting - DB

Design-build accounted for 1 outstanding rating, 5 above average, 14 average, 2 below average and 2 unsatisfactory. While design-bid-build totaled 2 outstanding, 27 above average, 55 average, 3 below average and no unsatisfactory ratings.

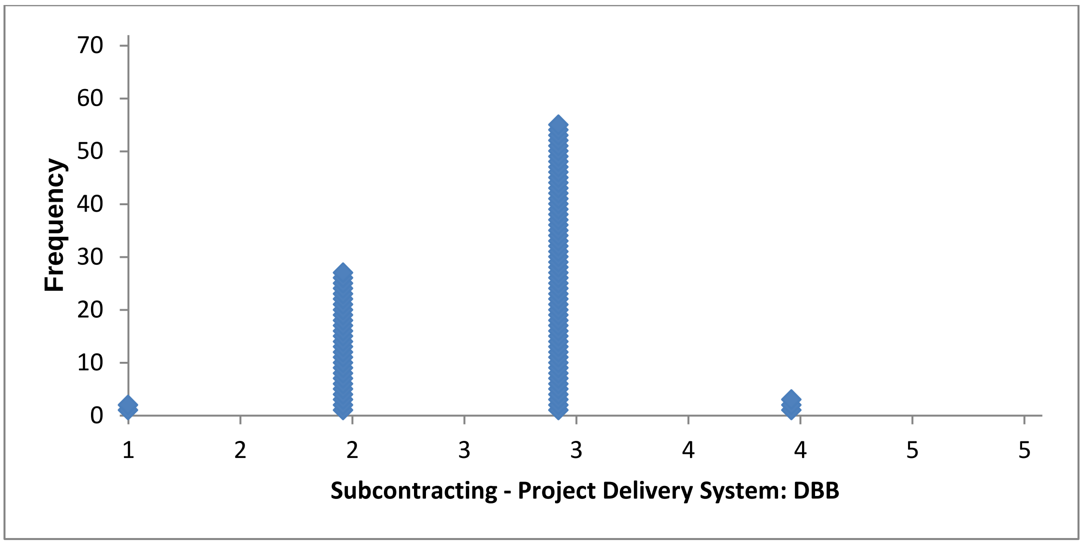


Figure 30 Dot Plot - Subcontracting - DBB

4.2.6.7 Planning & Scheduling

The subcontractor's planning and scheduling skill sets are evaluated by their ability to effectively anticipate project delays and plan to minimize the resulting schedule impact, report effectively their progress including variances based on their project schedule, resource plan, logistical plan. 16% (28) of the 175 total responses are attributed to DB with the remaining 84% (147) going to DBB. Seven outstanding, 62 above average, 88 average, 14 below average and 4 unsatisfactory ratings were returned by the 175 respondents for the planning and scheduling performance factor. Lower scores represent better performance.

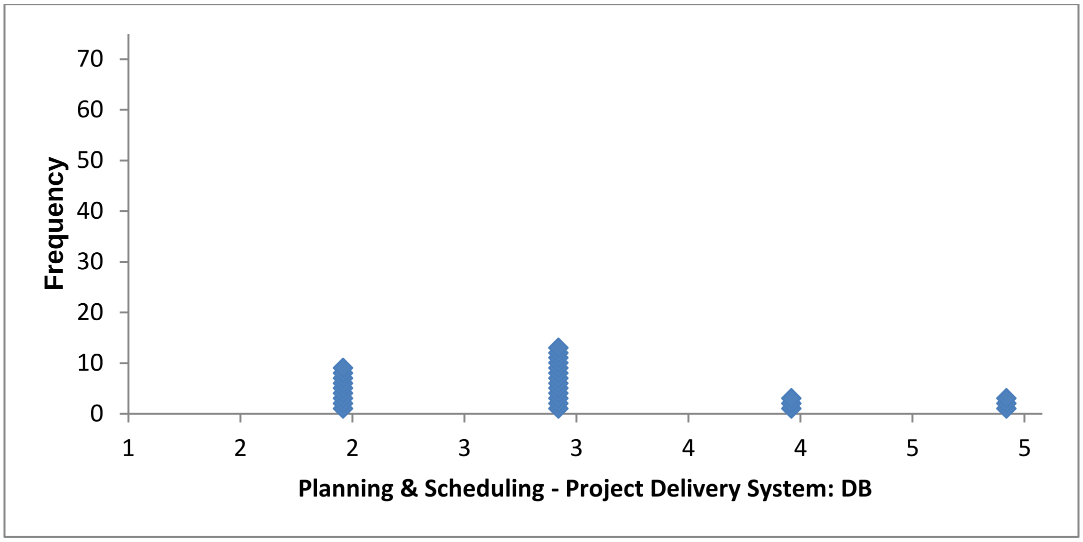


Figure 31 Dot Plot - Planning and Scheduling - DB

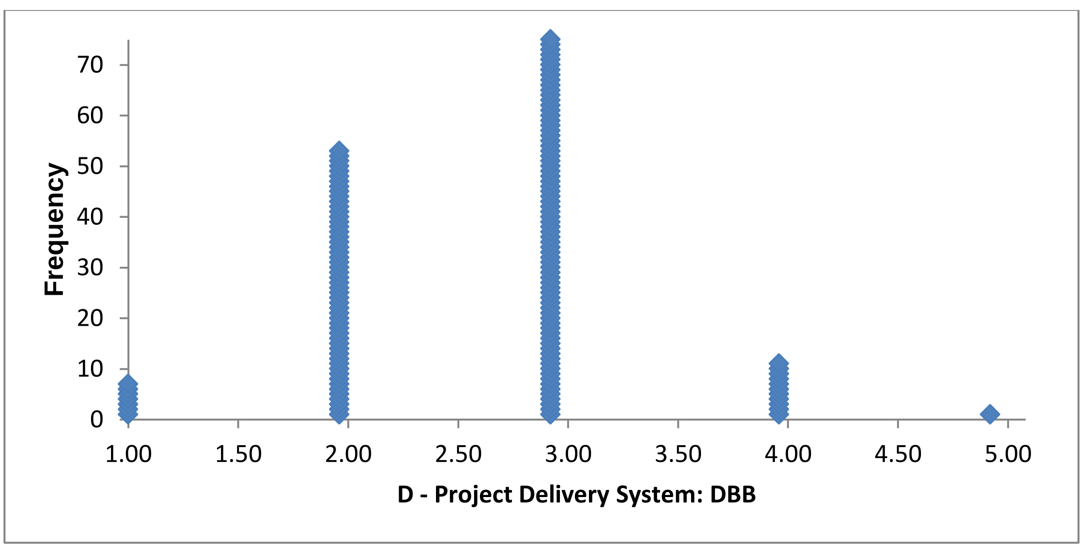


Figure 32 Dot Plot - Planning and Scheduling - DBB

DB scored 0 outstanding ratings followed by 9 above average, 13 average, 3 below average, and 3 unsatisfactory projects, whereas DBB claimed 7 outstanding ratings, 53 above average, 75 average, 11 below average and 1 unsatisfactory.

4.2.6.8 Quality

This matrix evaluates the contractor's overall quality performance based on the proactive efforts of their inspectors to comply with the project quality standards, resolve non-compliant conditions, and that the contractor maintained sufficient qualified quality staff to assure the contract requirements is fulfilled. One hundred seventy four responses yield 28 (16%) for DB and 146 (84%) for DBB. The overall quality matrix breakdown consists of 5 outstanding, 84 above average, 81 average, 4 below average and no unsatisfactory appraisals. Breaking the assessments down between delivery system, DB was assessed as 1 outstanding, 14 above average, 13 average and no below average contrasted with DBB with 4 outstanding, 70 above average, 68 average and 4 below average. Lower scores represent better performance.

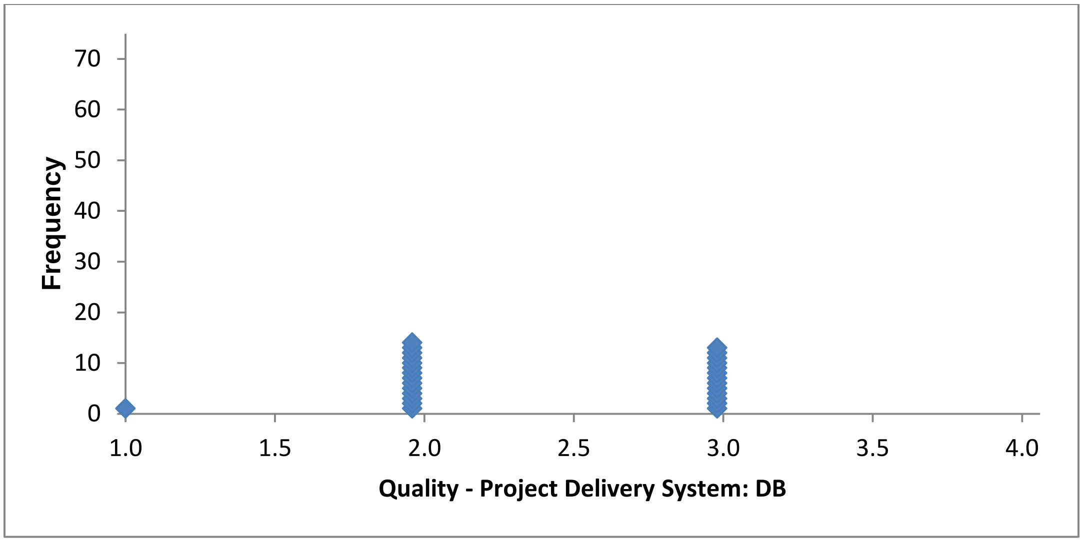


Figure 33 Dot Plot - Quality - DB

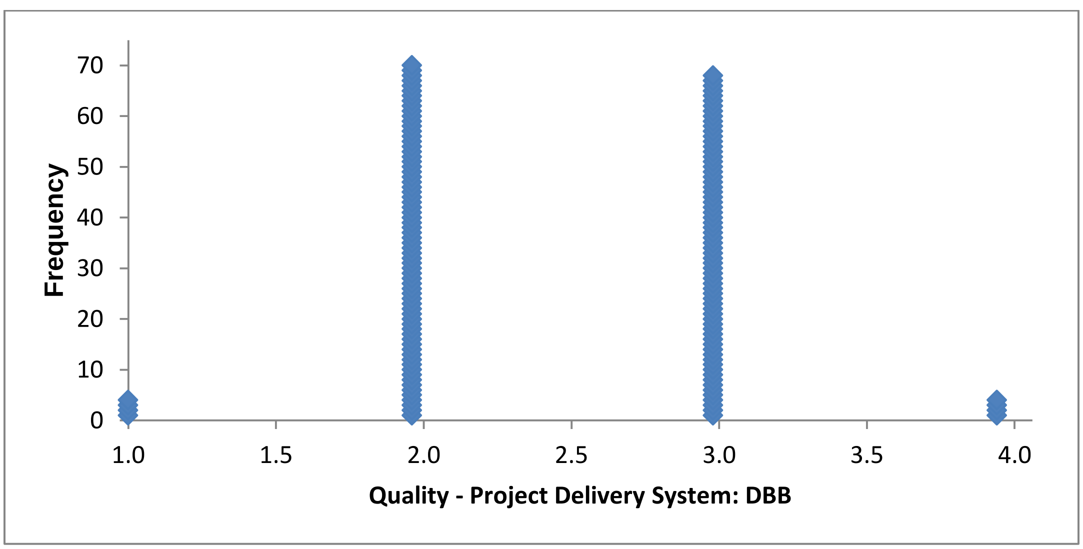


Figure 34 Dot Plot - Quality - DBB

4.2.6.9 Workmanship

This matrix evaluates the contractor's overall quality performance based on their technical competency and ability to communicate with the Owner; ability to meet special project requirements such as heavy lift planning and execution or combined space entry procedures; familiarity with project standards specifications and procedures. The 175 responses for Workmanship are divided by 28 (16%) going to DB and 147 (84%) to DBB. The 175 respondents returned overall rankings of 7 outstanding, 71 above average, 93 average, 4 below average, and zero unsatisfactory. Lower scores represent better performance.

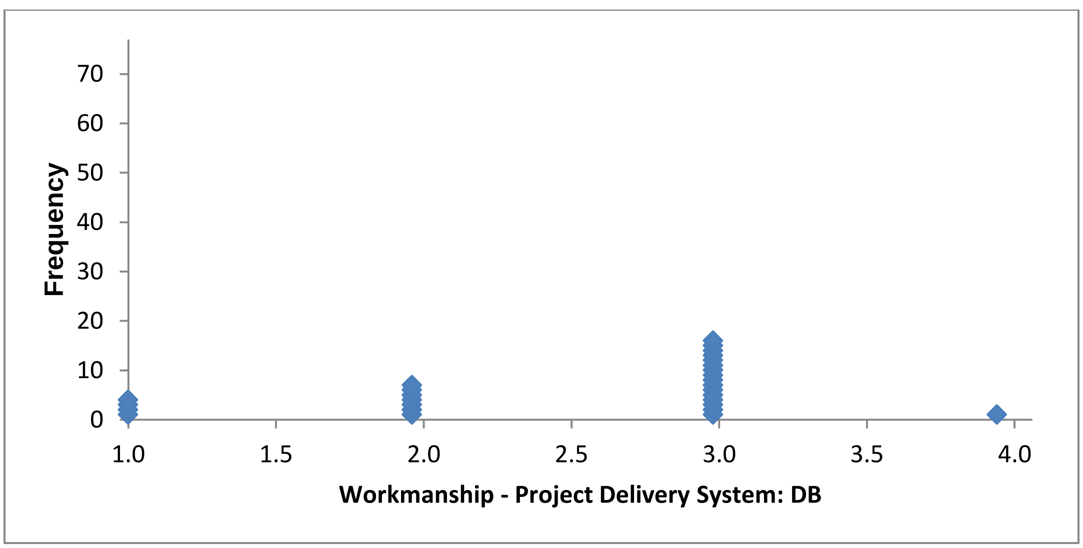


Figure 35 Dot Plot - Workmanship - DB

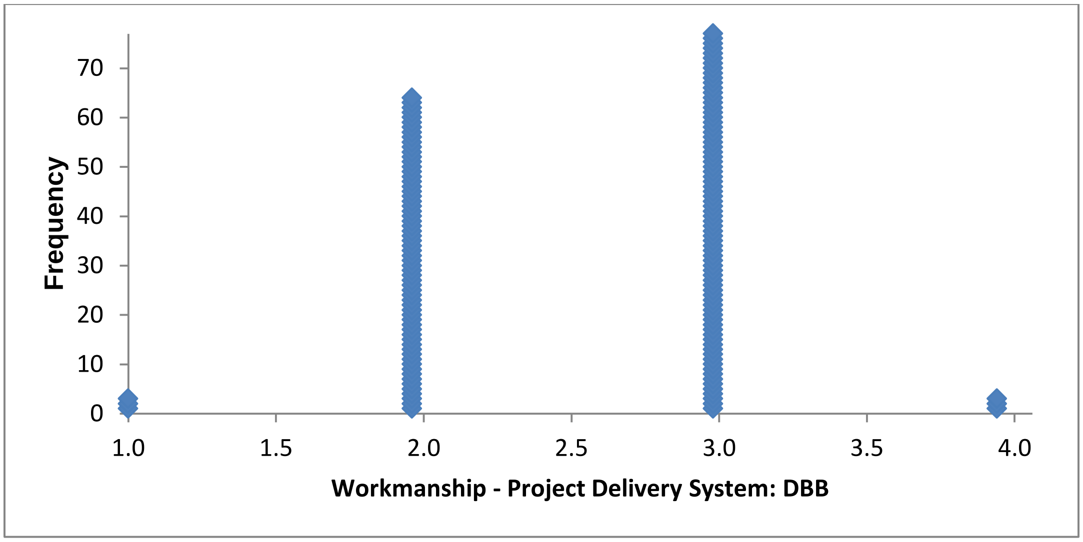


Figure 36 Dot Plot - Workmanship - DBB

The 28 DB projects were ranked as 4 outstanding, 7 above average, 16 average, 1 below average and zero unsatisfactory compared to the 147 DBB projects judged as 3 outstanding, 64 above average, 77 average, 3 below average and no unsatisfactory.

4.2.6.10 Material Procurement

The contractor is evaluated by how well their approved procurement plan is followed and deviations are reported and managed as well as material handling, testing, storage and the competence of material expeditors. Sixteen percent or 27 of the 171 evaluations were for DB with the remaining 84% (144) against DBB. DB earned 1 outstanding, 6 above average, 17 average, 2 below average, and 1 unsatisfactory scores while DBB earned 3 outstanding, 61 above average, 72 average, 7 below average, and 1 unsatisfactory ratings. Lower scores represent better performance.

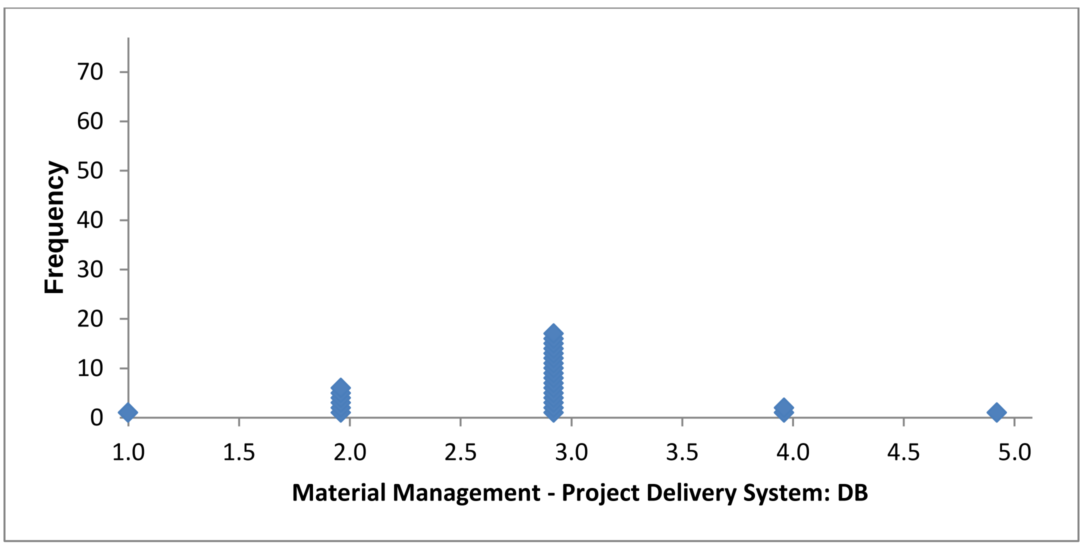


Figure 37 Dot Plot - Material Procurement - DB

DBB projects were graded as 4 outstanding, 67 above average, 89 average, 9 below average, and 2 unsatisfactorily by the 171 evaluators.

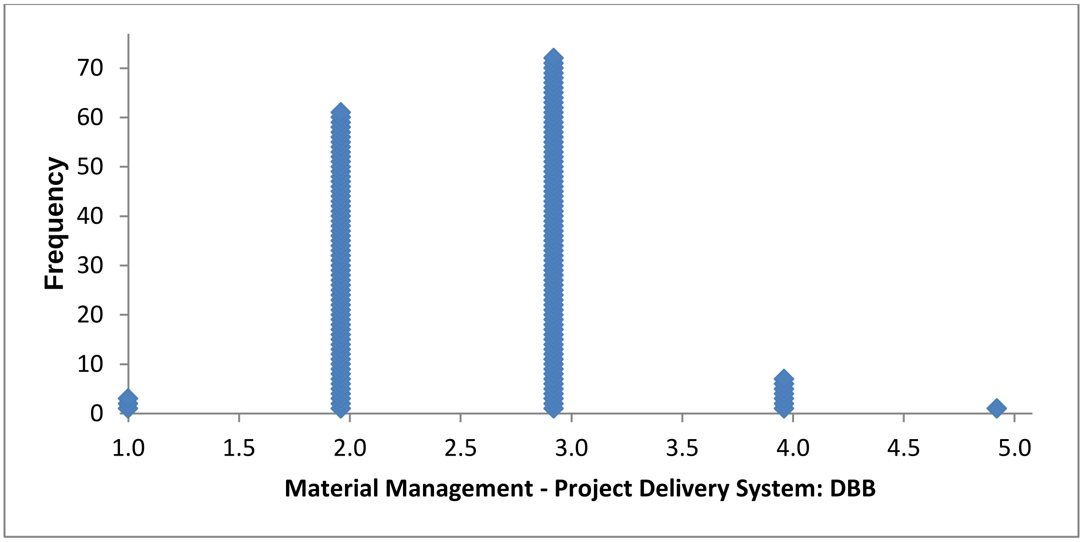


Figure 38 Dot Plot - Material Procurement - DBB

4.2.6.11 Cost Control

This matrix measures the contractor's ability to accurately manage project cost including owner invoices with supporting documentation; cost estimates are prepared professionally, timely, and with adequate detail; change requests are well documented and submitted timely; actively proposes value engineering improvements. Twenty seven or 16% DB combined with 138 (84%) equal the total dataset of 165 for the cost control performance indicator. Of the 165 total survey responses there were 5 outstanding, 67 above average, 90 average, 2 below average, and 1 unsatisfactory ratings were reported and distributed as DB having 1 outstanding, 6 above average, 19 average, zero below average and 1 unsatisfactory with DBB holding 4 outstanding, 61 above average, 71 average, 2 average and 0 unsatisfactory evaluations. Lower scores represent better performance.

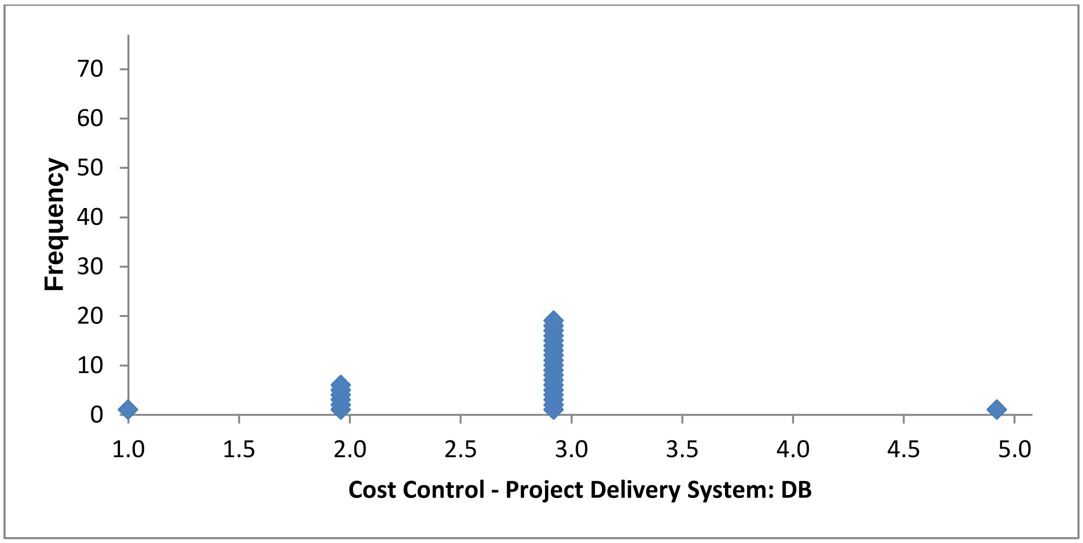


Figure 39 Dot Plot - Cost Control - DB

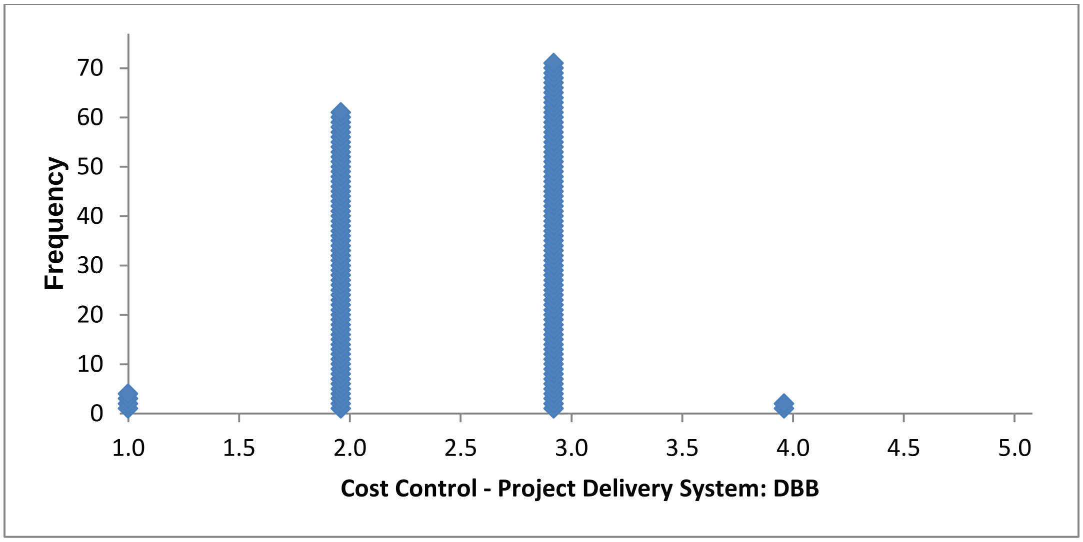


Figure 40 Dot Plot - Cost Control - DBB

4.2.6.12 Safety

The safety evaluation matrix reports the contractor's performance against the project established safety program including personal protective equipment use; proper use of tools and equipment; compliance with owner's safety regulations; housekeeping practices; safety meetings; emergency response drills; job skills competency training and certification; near miss reporting and investigation. The sample size for safety follows the general pattern of 17% (28) DB and 83% (140) DBB broken down by DB having 1 outstanding record, 9 above average, 17 average, no below average, and 1 unsatisfactory rating. DBB on the other hand had 7 outstanding projects, 54 above average, 74 average, 5 below average, and no unsatisfactory records to report. Lower scores represent better performance.

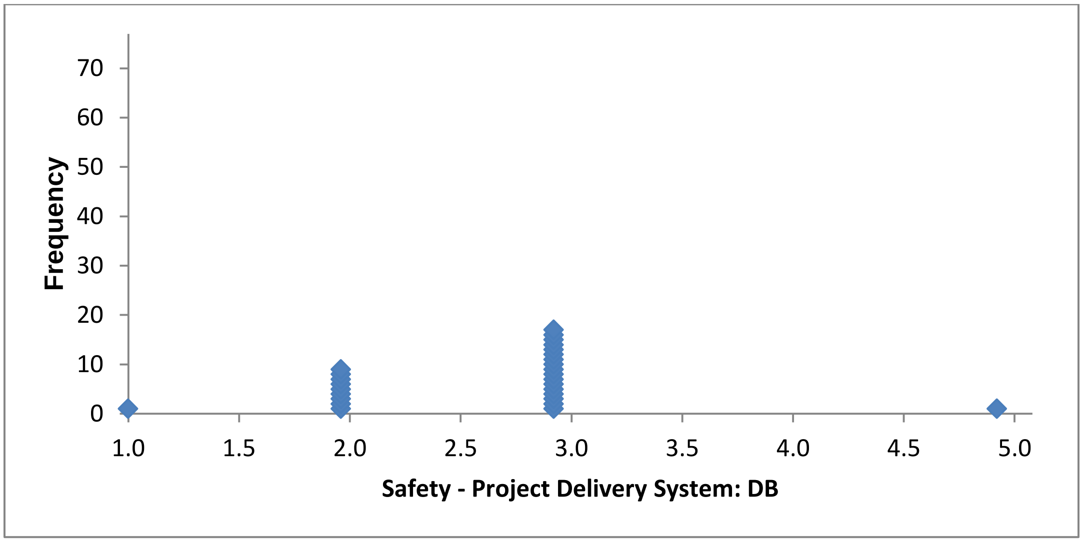


Figure 41 Dot Plot - Safety - DB

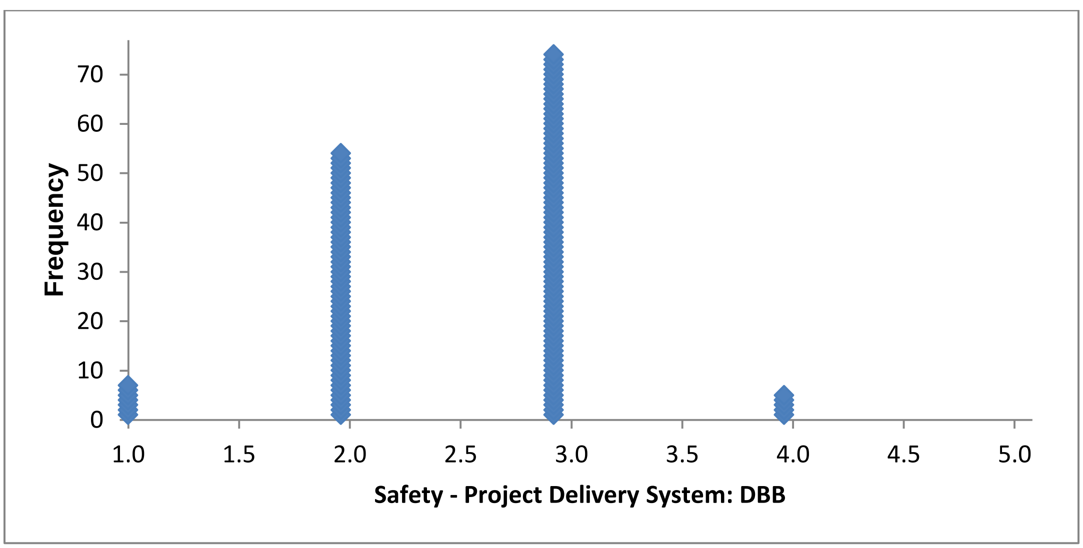


Figure 42 Dot Plot - Safety - DBB

4.2.6.13 Loss Prevention

Loss prevention is appraised based upon lost time injuries; motor vehicle accidents; unsafe driving practices; and medical coordination and support. The loss prevention dataset is the smallest with a total of 59 responses separated into 13 (22%) for DB and 46 (78%) going to DBB. Although the dataset is the smallest the ratings are the highest with DB earning 1 outstanding report, 3 above average, 9 average and no below or unsatisfactory ratings. DBB followed suit with 1 outstanding, 27 above average, 18 average and no below average or unsatisfactory evaluations. Lower scores represent better performance.

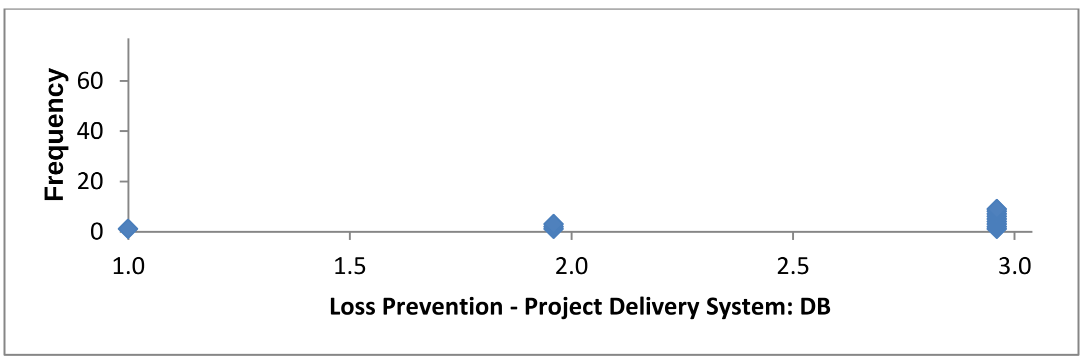


Figure 43 Dot Plot - Loss Prevention - DB

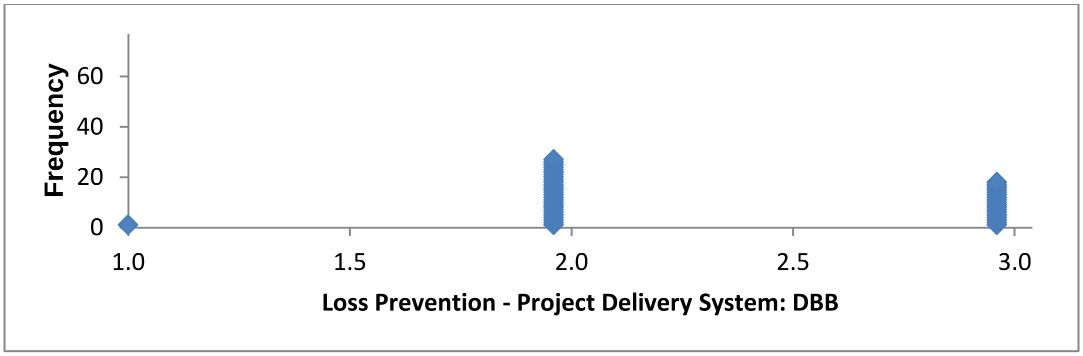


Figure 44 Dot Plot - Loss Prevention - DBB

CHAPTER 5

QUANTITATIVE RESULTS

5.1 Overview

To investigate the inferences between two independent project delivery systems DB and DBB, the Student's t-test or commonly called t-test, is used to test a hypothesis through the difference in means to see if they are statistically significant. A confidence level of 95% was used, for the reason that statistical analysis done within this range is broadly accepted in the construction industry. "Hypothesis testing measures the strength of evidence in the data for or against precise statements about population characteristics" (CII 1997). The null hypothesis (equation 4) for this study predicts the two project delivery systems are equal.

$$H_0: \mu_{DB} = \mu_{DBB} \qquad \text{Equation 4}$$

μ_{DB} represents the mean value for the DB sample and μ_{DBB} the mean value of DBB sample. The t test is then performed to test the null hypothesis and decide whether or not it should be rejected in favor of an alternate hypothesis defined in equation 5. Equation 5 states the mean values of the DB and DBB samples are unequal.

$$H_1: \mu_{DB} \neq \mu_{DBB} \qquad \text{Equation 5}$$

The critical region establishes the criteria to reject H_0. If the test result lies in this critical region then H_0 is rejected in favor of the alternative hypothesis H_1. A one tailed t-test looks for either an increase or decrease in the test parameter, where a two tailed t-test, as used in this analysis, looks for any change in the parameter either an increase or decrease and contains two critical regions of equal size. MiniTab16® and Sigma XL® statistical software packages were used to perform the analysis.

Note: Lower scores for performance indicators generally denote better performance and are identified by shaded cells.

5.2 Summary of Mean Performance Indicators by Project Delivery System

This section discusses the overall performance results for DB and DBB projects. With the exception of cost growth, change rate, and quality DBB performed better overall. When comparing Cost Growth there was a notable difference between DB and DBB with DB performing significantly better (p=0.0369).

Table 7 - Summary of Mean Performance Indicators by PDS

Metric[2]	DB	DBB	p Value
Cost Growth (%)	4.9*	7.0	**0.0369**
Change Rate	0.7†	1.9	**0.0000**
Schedule Growth (%)	72.9	67.5	0.5946
Management & Administration	2.6	2.6	0.9022
Equipment / Facilities	2.6	2.5	0.5256
Subcontracting	3.0	2.7	0.1629
Planning & Scheduling	3.0	2.6	0.0591
Quality	2.4	2.5	0.5909
Workmanship	2.5	2.5	0.7804
Material Procurement	2.9	2.6	0.1161
Cost Control	2.8	2.5	0.0750
Safety	2.7	2.6	0.3883
Loss Prevention	2.6	2.4	0.2294

* p Value <0.05

† p Value <0.01

[1]Statistical warning in Appendix A

[2] Metric definitions in Appendix B

DB projects significantly outperformed DBB project in the change rate metric by almost double with a p value of 0.0000.

Although there was not a statistically significant difference in the schedule growth metric with DB projects underperforming DBB projects. A review of how project delivery systems are defined for this study may be helpful in explaining these findings. A project is defined as DBB if the company performed either the design function only, the construction function only, or greater than 50% of either design or construction. Otherwise they will be categorized as DB (CII 2004). DBB contractors may have an advantage predicting schedule duration by managing only construction or only engineering risk events and not a combination of the two.

No difference was observed for the Management and Administration or the Workmanship metrics between DB and DBB delivery systems.

DBB tended to have better performance in the Equipment / Facilities, Subcontracting, Planning & Scheduling, Material Procurement, Cost Control, Safety, and Loss Prevention metrics, although there were no significance differences. Differences in Planning and Scheduling (p=0.0591), and Cost Control (p=0.0750), did approached significance, however.

5.3 Summary of Mean Performance Indicators by Cost Category

Table 8 summarizes the mean performance results for DB and DBB projects by Cost Category. In the less than $15 MM category DBB was dominate. Cost growth, change rate (p=0.0027), schedule growth, and quality all fell in favor of DB. There was no observed difference between delivery systems for the management & administration or workmanship performance factors. Although DBB performed better in 11 of the 13 factors studied, cost control being significantly better (p=0.0028), in the $15 to $50 MM category, DB performed better in 2 factors (change rate and loss prevention). The findings reveres in the greater than $50 MM category to DB generally performing better with the exception of safety and loss prevention factors showing observed differences in favor of DBB.

Within the cost category safety is the only factor with results dominated by DBB across all three categories. This behavior may be attributed to shorter schedule durations in the under $15 MM and $15 to $50 MM categories as well as project complexity. Caution should be used when interpreting of the safety findings for the $15 MM to $50 MM and over $50 MM categories due to the small sample sizes for these two categories.

Cost growth in the less than $15 MM category although not statistically significant falls in favor of DB while in the $15 to $50 MM category DBB's performance is observed to be slightly better. In the greater than $50 MM range differences between the delivery systems are found significantly in favor of DB (p=0.0421). The DB mechanism may have influenced the cost performance in the larger cost categories.

The DB change rate performance factor is found to consistently outperform DBB across all three metrics, significantly so in the less than $15 MM metric with a p value of 0.0027 and the $15 MM to $50 MM range approaching significant with a p = 0.0553.

Regarding Schedule Growth DB projects performed better in the smaller (less than $15 MM) sized projects and the larger projects (greater than $50 MM). But in the $15 MM to $50 MM category of projects DBB performed better.

Management and Administrative was mixed. No observed difference between DB and DBB in the less than $15 MM cost category. DBB exhibited better performance in the $15 MM to $ 50 MM category and DB significantly performed better (p=0.0154) than similarly classified DBB projects.

Equipment / Facilities, Subcontracting, and Planning & Scheduling performance metrics in the less than $15 MM and $15 to $50 MM cost categories DBB tended to perform better. Yet in the greater than $50 MM range DB outperformed DBB in all cases with Equipment / Facilities having a p value approaching significant (p=0.0577). Due to the small sample sizes in the $15 MM to $50 MM and greater than $50 MM ranges the findings should be interpreted with caution.

Quality performance was somewhat better for DB projects in the less than $15 MM category. However, DBB projects outperformed DB in the other two categories. Project delivery system did not seem to make a difference in the performance Workmanship matric.

Table 8 Summary of Mean Performance Indicators by Cost Category

Metric[2]	<15MM		15 - 50 MM[1]		>50 MM[1]		p Value		
	DB	DBB	DB	DBB	DB	DBB	<15mm	15-50MM	>50MM
Cost Growth (%)	6.1	7.2	7.7	7.2	2.7*	5.5	0.4652	0.8852	**0.0421**
Change Rate	1.3†	2.3	0.4	0.9	0.3	0.4	**0.0027**	0.0553	0.5325
Schedule Growth (%)	57.4	64.6	91.4	60.2	78.0	100.0	0.5476	0.1551	0.3671
Management & Administration	2.6	2.6	3.5	2.3	2.0*	3.3	0.9065	0.1917	**0.0154**
Equipment / Facilities	2.7	2.5	2.7	2.1	2.0	2.8	0.4217	0.2763	0.0577
Subcontracting	2.9	2.7	3.3	2.6	2.7	3.0	0.2758	0.1763	0.4226
Planning & Scheduling	3.0	2.6	3.3	2.4	2.7	3.8	0.0717	0.4399	0.1369
Quality	2.4	2.5	2.7	2.2	2.3	3.0	0.5260	0.3527	0.1835
Workmanship	2.5	2.5	2.7	2.3	2.0	3.3	0.9638	0.4601	0.1853
Material Procurement	2.8	2.6	3.3	2.5	3.0	3.8	0.3165	0.1229	0.0577
Cost Control	2.9	2.5*	3.0	2.0†	2.0	3.0	**0.0440**	**0.0028**	0.2254
Safety	2.7	2.6	2.7	2.1	2.7	2.0	0.6187	0.2763	0.3910
Loss Prevention	2.7	2.4	2.0	2.5	2.7	2.0	0.2700	--	0.6410

* p Value <0.05

† p Value <0.01

[1] Statistical warning in Appendix A

[2] Metric definitions in Appendix B

5.4 Summary of Mean Performance Indicators by Pricing Method

Table 9 summarizes mean performance results by pricing method. Due to small unit rate sample sizes the interpretation of the results for all comparisons between project delivery systems should be approached with caution. Eight of the 13 performance indicators categorized as lump sum indicate DBB perform better. No observed difference was found between the remaining 3 factors. The two indicators found in favor of DB were statistically significant. The unit rate category findings are mixed with 5 performance indicators resulting in DB projects performing better, 5 performance indicators resulting in DBB projects performing better and 3 indicators where delivery system did not seem to have an influence on performance.

Table 9 Summary of Mean Performance Indicators by Pricing Method

Metric[2]	Lump Sum		Unit Rate[1]		p Value	
	DB	DBB	DB	DBB	Lump Sum	Unit Rate
Cost Growth (%)	5.0*	7.3	2.8	1.1	**0.0234**	0.6588
Change Rate	0.7†	2.0	0.0	0.0	**0.0000**	0.3016
Schedule Growth (%)	74.0	68.2	28.2	50.9	0.5640	0.5736
Management & Administration	2.6	2.6	2.0†	2.9	0.8466	**0.0010**
Equipment / Facilities	2.6	2.5	2.5	3.0	0.4323	0.5000
Subcontracting	3.0	2.7	3.0	3.0	0.1722	--
Planning & Scheduling	3.0	2.6*	2.5	2.7	**0.0470**	0.7566
Quality	2.5	2.5	2.0†	2.7	0.8710	**0.0082**
Workmanship	2.5	2.5	3.0	2.9	0.6903	0.3559
Material Procurement	2.8	2.6	3.0	2.9	0.1417	0.3559
Cost Control	2.8	2.5	3.0	2.7	0.1055	0.1723
Safety	2.7	2.5	3.0	2.7	0.4784	0.1723
Loss Prevention	2.6	2.3	3.0	3.0	0.2647	--

* p Value <0.05

† p Value <0.01

[1]Statistical warning in Appendix A

[2] Metric definitions in Appendix B

Within pricing method cost growth was found significantly lower for DB (p = 0.0234) projects however, the reverse is true for unit rate contracts although not significant DBB outperforms DB. Change order rate for lump sum contracts was dominated by the DB delivery system (p = 0.0000) while there was no observed difference found in the unit rate category. Lump sum DBB projects returned better schedule performance, while DB projects demonstrated better schedule performance on unit rate contracts. This may be attributed to the project's ability to forecast duration better because it included only either construction or design. Although there was no significant difference between lump sum Management & Administrative performance, there was a significant difference (p=0.0010) for DB unit rate projects. Similarly no significant difference was found for lump sum

Quality performance, but DB performed better (p=0.0082) in the unit rate category.

Among unit rate contracts no observed difference in performance was found between project delivery systems for Management & Administration, Quality, and Workmanship. Likewise project delivery system did not seem to influence Loss Prevention performance for unit rate contracts.

Equipment / Facilities, Subcontracting, and Planning & Scheduling performed slightly better on DBB lump sum projects with the exception of Planning & Scheduling which performed significantly better (p=0.0470). DBB projects had better scores for both lump sum and unit rate projects in Material Procurement, Cost Control, and Safety.

5.5 Summary of Mean Performance Indicators by Selection Method

This section discusses the mean performance results for DB and DBB projects by selection method. The pre-qualified category DBB dominated 8 of the 13 indicators. Neither DBB nor DB pre-qualified projects had an advantage over the other for the remaining 3 indicators. The open solicitation category scores were mixed with DB performing better in 7 out of 13 indicators with only Loss Prevention scores reporting no difference. Regarding sole source projects 8 of 13 indicators performed better under the DB project delivery system, with Loss Prevention scores not showing a difference between DB and DBB. Caution is advised when interpreting the results of the open solicitation and sole source categories due to small sample sizes.

With regard to Cost Growth, DB projects tended to exhibit better performance approaching significant in the pre-qualified ($p = 0.0651$) and open solicitation ($p = 0.0599$) categories. The sole source category was observed in favor of DB as well.

Pre-qualified DB projects performed significantly lower than DBB in the change order rate factor with a p value of 0.0000. The same holds true for the open solicitation category with DB outperforming DBB significantly ($p = 0.0233$). Although not significant the findings reverse for sole source contracts with DB scores being higher indicating lower performance.

With reference to schedule growth pre-qualified and open solicitation DBB projects had better scores. Although not statistically significant, again the trend reverses for sole source projects with DB schedule growth being less than half the score of DBB.

Project delivery system did not seem to influence the outcome of the Management & Administration, Quality, and Workmanship performance indicators for pre-qualified projects. The same is found for Loss Prevention in the open solicitation category. However, DB significantly ($p=0.0127$) underperformed DBB for Loss Prevention pre-qualified contracts.

DBB performed better than DB in the Subcontracting, and Cost Control indicators for all three selection methods, whereas DBB performed worse in Management & Administrative, Equipment / Facilities, Quality, and Safety factors for both open solicitation and sole source selection methods. With open solicitation, Equipment / Facilities performing significantly ($p=0.0133$) better.

Considering the Planning & Scheduling performance indicator DBB showed better performance for the pre-qualified (approaching statistically significant $p=0.0753$) and sole source selection methods. DB performed slightly better than DB in the open solicitation method.

Workmanship and Material Procurement indicators followed a similar pattern with DBB performing better under the open solicitation selection method and worse by the sole source method.

Table 10 Summary of Mean Performance Indicators by Selection Method

Metric[2]	Pre-qualified		Open-Low Bid Wins[1]		Sole Source[1]		p Value		
	DB	DBB	DB	DBB	DB	DBB	Pre-Qual	Open	SS
Cost Growth (%)	5.0	7.0	3.8	7.1	5.4	5.5	0.0651	0.0599	0.9779
Change Rate	0.7†	1.9	0.6*	2.0	0.9	0.7	**0.0000**	**0.0233**	0.7099
Schedule Growth (%)	75.9	68.3	43.6	39.3	67.3	168.3	0.4901	0.8314	0.2289
Management & Administration	2.6	2.6	2.0	2.3	2.7	3.0	0.9640	0.3466	0.7418
Equipment / Facilities	2.7	2.5	2.0*	2.6	2.3	3.0	0.2915	**0.0133**	0.1835
Subcontracting	3.0	2.7	2.5	2.3	3.5	3.0	0.2881	0.8211	0.5000
Planning & Scheduling	3.0	2.6	2.5	2.6	3.3	3.0	0.0753	0.9392	0.7418
Quality	2.5	2.5	2.0	2.4	2.0	2.5	0.8310	0.1038	0.5799
Workmanship	2.6	2.6	2.5	2.3	2.0	3.0	0.9366	0.8211	0.2254
Material Procurement	2.9	2.6	3.0	2.4	2.7	3.0	0.1492	0.0509	--
Cost Control	2.8	2.5	2.5	2.3	2.7	2.5	0.0892	0.8136	0.8278
Safety	2.8	2.6	2.5	2.6	2.0	2.5	0.1360	0.9335	0.5799
Loss Prevention	2.8	2.4*	2.5	2.5	--	1.0	**0.0127**	1.0000	--

* p Value <0.05

† p Value <0.01

[1] Statistical warning in Appendix A

[2] Metric definitions in Appendix B

5.6 Summary of Mean Performance Indicators by Industry Group

This section compares performance indicators by industry . Table 11 summarizes the mean outcomes by project delivery system and shows results being predominantly in favor of DBB for commercial projects yet for industrial projects the results are mixed. Six of the performance indicators for industrial projects were found in favor of DBB, 4 in favor of DB and 3 showing no observed difference, contrasted with the commercial project findings of 9 DBB projects showing better performance, 2 in favor of DB with the remaining 2 returning no observed difference.

DB performed significantly better in the cost growth metric for industrial projects with a p value of 0.0023. The findings reverse for commercial projects with DB performing slightly worse than DBB.   These findings are consistent with the results of other studies and is most likely a function of the DBB mechanism.

For the change order rate performance indicator, DBB underperformed DB by a significant (p=0.0000) difference for the industrial group, and remained consistent for the commercial group with DB performance approaching significance (p = 0.0662).

DBB industrial and commercial projects had better mean performance scores for schedule growth. While the findings were not statistically significant the differences between the scores were close. And among both industry groups Subcontracting DBB projects performed better resulting in a p value of 0.0019 for the industrial group.

Seemingly project delivery system did not have an influence on performance for Management & Administration, Equipment / Facilities, or Quality indicators for the industrial group nor for Quality or Workmanship in the commercial group.

DB industrial projects observed better performance for Workmanship and Safety as well as DB commercial projects Management & Administration. Whereas DBB industrial projects observed better performance for Planning & Scheduling, Material Procurement, Cost Control and Loss Prevention in like manner for commercial projects with Planning & Scheduling, Material Procurement, Cost Control, Safety, and Loss Prevention performing better.

Table 11 Summary of Mean Performance Indicators by Industry Group

Metric[2]	Industrial		Commercial		p Value	
	DB	DBB	DB	DBB	Industrial	Commercial
Cost Growth (%)	3.5†	6.4	8.9	8.5	**0.0023**	0.8775
Change Rate	0.5†	1.7	1.3	2.4	**0.0000**	0.0662
Schedule Growth (%)	76.1	70.6	63.5	60.1	0.6540	0.8431
Management & Administration	2.6	2.6	2.6	2.7	0.9857	0.7870
Equipment / Facilities	2.5	2.5	2.7	2.5	0.7233	0.6531
Subcontracting	3.2	2.7†	2.8	2.7	**0.0019**	0.8427
Planning & Scheduling	3.0	2.7	3.0	2.6	0.1506	0.2174
Quality	2.5	2.5	2.4	2.4	0.7197	0.8509
Workmanship	2.5	2.6	2.5	2.5	0.9306	0.7931
Material Procurement	2.8	2.6	2.9	2.6	0.2830	0.2603
Cost Control	2.7	2.6	2.8	2.4	0.3260	0.1262
Safety	2.5	2.6	2.8	2.5	0.7923	0.1644
Loss Prevention	2.6	2.4	2.8	2.4	0.4693	0.2940

* p Value <0.05

† p Value <0.01

[1]Statistical warning in Appendix A

[2] Metric definitions in Appendix B

5.7 Summary of Mean Performance Indicators by Ownership

Table 12 provides a summary of the mean performance findings for DB and DBB projects by company ownership. It may be beneficial to review the definition of company ownership which is defined by nationality. In order for a company to be considered Saudi Arabian it must be 100% owned by a Saudi national citizen/s otherwise it is classified as multi-national. Due to the small sample sizes for the 10 multi-national subjective performance indicators judgment is advised when interpreting the findings.

Both Saudi Arabian and multi-national ownership categories are dominated by the DBB delivery system. Saudi Arabian DBB projects perform better in 8 of the 13 indicators, DB performed better for 3 indicators and 2 there was no observed difference. Similarly 7 of 13 success indicators performed better as DBB, 5 performing better as DB, and 1 factor the delivery system did not seem to have an influence on performance. Table 12 details the results.

Table 12 Summary of Mean Performance Indicators by Ownership

Metric[2]	Saudi		Multi-National[1]		p Value	
	DB	DBB	DB	DBB	Saudi	Multi
Cost Growth (%)	5.5	7.2	4.6	6.2	0.2622	0.2551
Change Rate	1.1†	2.2	0.5	0.7	**0.0006**	0.0994
Schedule Growth (%)	74.8	65.4	71.6	76.0	0.4972	0.7791
Management & Administration	2.6	2.6	2.5	2.5	0.9928	0.9212
Equipment / Facilities	2.6	2.5	2.6	2.3	0.6254	0.3512
Subcontracting	3.0	2.7	2.9	2.7	0.2355	0.6763
Planning & Scheduling	2.9	2.6	3.1	2.5	0.2001	0.2154
Quality	2.4	2.5	2.4	2.5	0.5207	0.9751
Workmanship	2.6	2.6	2.2	2.4	0.7257	0.6870
Material Procurement	2.8	2.6	3.0	2.5	0.3696	0.1558
Cost Control	2.9	2.5*	2.6	2.3	**0.0471**	0.4487
Safety	2.7	2.6	2.6	2.2	0.3887	0.3948
Loss Prevention	2.9	2.4†	2.2	2.0	**0.0075**	0.7304

* p Value <0.05

† p Value <0.01

[1]Statistical warning in Appendix A

[2] Metric definitions in Appendix B

Cost growth for both ownership categories, Saudi Arabian and multi-national, DBB projects underperformed DB. DB projects with respect to the change order rate were found to have similar success for both classes of ownership. Saudi owned companies performed significantly (p = 0.0006) better than DBB for change order rate while multi-national company change order rate scores were not significant they still prevailed over DBB. The observed difference in Schedule Growth for Saudi Arabian owners was in favor of DBB performing better than DB. Although there was no significant difference, multi-national DB projects out performed DBB projects.

Among both Saudi Arabian and multi-national owners project delivery system did not seem to make a difference in performance for the Management & Administration indicator. DBB performed better in the Equipment / Facilities, Subcontracting, Planning & Scheduling, Material Procurement and Safety factors for both owner categories. DBB performed significantly better in the Cost Control (p=0.0471) and Loss Prevention (p=0.0075) factors for the Saudi Arabian ownership category, and DBB had better observed performance in the multi-national category. Saudi Arabian and multi-national DB projects narrowly performed better than DBB for the Quality performance indicator.

CHAPTER 6

DISCUSSION

6.1 Introduction

Chapter 6 synthesizes the findings of this research effort. Data was collected and analyzed for construction performance indicators from diverse projects with a geographical distribution throughout the Kingdom of Saudi Arabia. All projects were administered by the same organization thus removing the variability of different agencies from the study (Minchin et al. 2013) as well as having a sample size large enough to conduct the Student's t test.

The overall results of this study (Tables 7 & 13) show statistically significant differences in two of the objective performance indicators measured, cost growth and change order rate, to be in favor of DB while DBB schedule growth scores were found to be lower than DB indicating better performance. Based simply on observed differences in 7 of the 10 subjective indicators, performance was found better for the DBB delivery system. Project delivery system did not seem to have an effect on 2 indicators and the remaining indicator (quality) returned a score in favor of the DB delivery system.

Table 13 Summary of Overall Performance Indicators

Metric[2]	PDS	p Value
Cost Growth (%)	DB*	**0.0369**
Change Rate	DB†	**0.0000**
Schedule Growth (%)	DBB	0.5946
Management & Administration	--	0.9022
Equipment / Facilities	DBB	0.5256
Subcontracting	DBB	0.1629
Planning & Scheduling	DBB	0.0591
Quality	DB	0.5909
Workmanship	--	0.7804
Material Procurement	DBB	0.1161
Cost Control	DBB	0.0750
Safety	DBB	0.3883
Loss Prevention	DBB	0.2294

* p Value <0.05

† p Value <0.01

-- No observed difference

[2] Metric definitions in Appendix B

6.2 Cost Growth

Overall DB projects largely exhibited better performance in cost related metrics with the exception of the unit rate, commercial, projects between $15MM and $50MM. Caution should be exercised interpreting the statistically small sample of 2 DB and 9 DBB (Table 16) for the unit rate pricing method. Ibbs, et al. (2003) found the benefit of cost effects were not as pronounced between DB and DBB.

Minchin et al. (2013) conculded “the DBB method was more consistent and reliable in matters of cost than the DB method”. Whereas the 2004 CII study observed owner DB projects performed better while there was no significant difference between the two delivery systems observed for contractor submitted projects. Riley et al. (2005) concluded overall cost growth due to DB change orders was found to be lower than DBB. In 2009 Rosner and Hale published reports finding cost growth performance to be better in DB projects than DBB.

6.3 Number of Contract Changes

In all project nature categories the findings were in favor of DB for the number of contract changes metrics with the exception of sole source projects. The Rosner (2009) study found overall DB prevailed in the number of contract modifications per million dollar indicator. Riley (2005) concluded DB projects reduced the number of field generated contract change orders. For contract changes, CII (2004) determined both contractor and owner design-build projects performed better.

6.4 Schedule Growth

The DBB delivery system exhibited overall better schedule performance than DB with the exception of sole source, multi-national, projects less than $15MM and greater than $50MM in size. Caution should be exercised interpreting the statistically small samples of 2 DB and 9 DBB (Table 16) for the unit rate pricing method as well as 5 DB and 4 DBB sole source projects (Table 17). The Construction Industry Institute (CII 2004) reported owner submitted DB projects to show better schedule performance however, contractor submitted DBB projects significantly outperformed DB projects (CII 2004). Rosner (2009) also concluded “DBB performed significantly better in terms of total project time”, while in 2013 Minchin reported “little to no difference between the two systems in the area of time (duration) performance…DB is the same or slightly better than DBB depending on the test results consulted”. Contrasted with the Ibbs (2003) study finding a schedule benefit of using the DB delivery system.

6.5 Management & Administration

Overall there was no difference observed between project delivery systems for the management & administration performance metrics however, the results were mixed within the five data subsets.

6.6 Equipment / Facilities

DB projects again fared the worst for the equipment / facilities performance metrics excluding unit rate projects greater than $50MM in base value, either sole source or open solicitation.

6.7 Subcontracting

The use of the DB delivery system tended to yield better performance for projects greater than $50MM in contract value. All other categories were dominated by the DBB delivery system.

6.8 Planning & Scheduling

Overall DBB projects performed better with the exception of unit priced projects greater than $50MM selected by open solicitation.

6.9 Quality

Quality is the single performance factor where DB prevailed overall excluding projects between $15MM and $50MM dollar range. There was no observed difference between the delivery systems for lump sum pricing method, pre-qualified selection method, industrial or commercial industry groups.

6.10 Workmanship

The performance advantage of one delivery system over the other does not seem to make a difference in workmanship overall as well as in the less than $15MM cost category, lump sum pricing method, pre-qualified selection method, commercial industry group, or Saudi ownership. However, DBB prevailed in projects which fell into the $15MM to $50MM cost category, unit rate pricing method, and open solicitation selection. DB performed better on projects greater than $50MM, which were sole source, industrial, multi-national.

6.11 Material Procurement

It was observed that DBB offered overall better performance. Yet in projects over $50MM and sole source projects the observation reversed.

6.12 Cost Control

Although DBB tended to perform better in the cost control metric overall DB was observed to perform better in the greater than $50MM dollar cost category.

6.13 Safety

Within the safety performance metric industrial projects, open solicitation, and sole source were observed to perform better under the DB delivery system. Although there were no statistical differences between the two delivery systems DBB consistently was observed to perform better overall as well as the remaining other categories.

The CII (2004) study observed no statistical difference between DB and DBB delivery systems for either owner or contractor submitted projects.

6.14 Loss Prevention

Based on observed differences overall, the loss prevention performance was better for DBB projects than DB. The breakdown for projects between 15 and 50MM dollars fell in favor with DB. For unit rate, open solicitation, and sole source categories there was no observed difference.

CHAPTER 7

SUMMARY AND CONCLUSIONS

7.1 Introduction

In this chapter, a summary of the thesis is presented followed by conclusions of the investigation, and recommendations for future studies are made.

7.2 Summary

The purpose of this thesis was to study the relationship between project performance and the delivery system used to execute them in the unique Saudi Arabian construction environment. To achieve this purpose an objective of statistically quantifying the effects that project delivery systems have on performance was established through analyzing 13 indicators being: (1) management / administration, (2) equipment / facilities, (3) subcontracting, (4) planning / scheduling, (5) quality program, (6) technical competence / workmanship, (7) material procurement, (8) cost control (9) safety, (10) loss prevention, (11) cost growth, (12) schedule growth, and (13) change order rate.

This objective was accomplished by testing the hypothesis that design-build and design-bid-build delivery systems perform equally, and then comparing the results to other published studies having similar research objectives.

This study uniquely contrasts the existing body of knowledge consisting predominantly of U.S. projects and contractors to Saudi Arabian projects. Another unusual aspect of this investigation is a rare insight into the performance of Saudi owned construction companies based on an infrequently used combination of performance indicators.

While some delivery systems may be better suited than others for the Saudi Arabian construction contracting environment, the Design-Build and Design-Bid-Build delivery systems have a proven history. Design-Bid-Build is a construction project delivery system which separates the design and construction functions. Design-Bid-Build consists of three distinct main phases; design, bidding or tender, and construction phases with clear lines defining the rolls and responsibilities of the project participants. Design-Build is a system which combines the responsibilities of the designer and constructor producing a single point of accountability to the owner.

The methodology used in this examination is broken down into the following phases:

Phase I: Literature Review

Phase II: Data Collection & Preparation

Phase III: Data Analysis

Phase I: A review of recently published literature yielded an understanding of the diverse quantitative and qualitative indicators employed by project owners to measure the health of their construction projects coupled with the analytical techniques applied by previous researchers to evaluate project performance.

Phase II: Data on 292 randomly selected capital construction projects geographically distributed throughout the Kingdom was collected from one of Saudi Arabia’s largest project owners.

Phase III: Inferences between the two project delivery systems DB and DBB were investigated by first dividing the overall data into 5 categories: (1) base contract cost, (2) pricing method, (3) contract selection method, (4) industry group, and (5) company ownership. Secondly; the 13 performance indicators mentioned above were tested by applying the Student’s t-test by category.

Of the 292 projects studied, 88 projects or 30% were categorized as DB for which the contractor performed greater than 50% of the design and construction effort, with the remaining 204 projects or 70% defined as DBB.

7.3 Conclusions

Considering the overall dataset the results of this study show that DBB is a better delivery system for constructing projects based on the overall13 performance metrics.

Schedule growth, equipment / facilities, subcontracting, planning / scheduling, material procurement, cost control, safety, and loss prevention number the indicators in favor DBB. The findings indicate DBB projects will take significantly less time (5.4%) to construct and should have more predictable completion dates on average.

DB projects performed better for number of contract changes, cost growth, and quality, indicating cost containment is 2.1% better achieved through use of DB.

The remaining two metrics management / administration and workmanship showed no difference between delivery systems therefore; remain neutral in the decision process.

7.3.1 Cost Category

- Within the data sample of projects less than $15 MM category the overall results are mixed between DB and DBB. The DB delivery system performs as one might expect by reducing cost growth, change order rate, and schedule growth. The statistical comparisons between the two systems resulted in a difference in cost growth savings of 15.3%; change order rate significantly reduced by 43.5%; and projects completed quicker by 11.2%. The overall average difference between the combined subjective measures is 3.7% lower for DBB.

- The data sample of projects between $15MM – $50MM are more pronounced in favor of DBB. Eleven of the 13 indicators are found in favor of DBB consisting of 2 objective indicators and 9 subjective. Cost and schedule growth are lower using the DBB delivery system, with change order rate lower using DB. The statistical comparisons between the two systems resulted in a cost growth reduction of 6.5% and schedule reduction of 34.1% by using the DBB delivery system. There were 55.6% fewer change orders per million dollars of base contract value for DB. The overall average difference between the combined subjective measures is 20.7% lower for DBB.

- Within the data sample for projects greater than $50MM the pattern reverses in favor of DB. The statistical comparisons between the two systems resulted in a statistically significant difference in cost growth savings of 50.9%; change order rate reduced by 25.0%; and projects completed 22.0% quicker. The overall average difference between the combined subjective measures is 20.0% lower for DB. Safety and loss prevention were found in favor of DBB.

7.3.2 Pricing Method

- Within the data sample for lump sum DB projects, cost growth and change order rate are significantly lower 31.5% and 65.0% respectively. While DBB projects are completed 7.8%% faster and the overall average difference between the combined subjective measures score is 7.4% lower for DBB.

- Within the data sample for unit price cost growth is 60.7%% lower for DBB projects however, schedule growth is 44.6% lower for DB projects. For the overall average difference between the combined subjective measures is 3.4% lower for DBB. There is no difference between delivery systems for the change order rate category.

7.3.3 Selection Method

- Within the selected data sample of pre-qualified DB projects the statistical comparison for sample means show that change order rate is significantly lower by 63.2%. Cost growth for DB projects is 28.6% lower as well. Schedule growth is found to be 10.0%% lower in DBB projects. The overall combined difference between the subjective metric is 7.1% in favor of DBB.

- Within the open bidding – low bid wins data sample DB projects experience a cost savings of 46.5% over DBB with a change order rate of 70.0% lower as well. DBB projects take 9.9% less time to complete. Comparing the overall combined difference between the subjective metric there is no difference.

7.3.4 Industry Group

- Within the selected sample for industrial projects the statistical results are mixed. The statistical comparisons for sample means indicated that cost growth (45.3%) and change order rates (70.6%) are significantly lower for DB, yet DBB projects are completed 7.2% faster. The overall combined difference between the subjective metric is 7.4% in favor of DBB.

- Within the selected sample for commercial projects the statistical results are overall in favor of DBB. The statistical comparisons for sample means indicated that cost growth was lower by 4.5% in DBB projects. Likewise DBB projects were delivered 5.4% quicker than DB. There were 45.8% fewer change orders per $1MM of base contract value written for DB projects. The overall combined difference between the subjective matrix is 7.4% lower in favor of DBB.

7.3.5 Company Ownership

- Within the company ownership data sample Saudi owned companies executing DB projects showed a lower cost growth by 23.6% and a 50.0% significantly lower change order rate. But time to complete DBB projects was 12.6% shorter. The overall combined difference between the subjective metric is 7.1% in favor of DBB.

- Within the data sample for multi-national owned companies, cost growth is 25.8% lower; there are 28.6% fewer change orders issued; and schedule growth is reduced by 2.8% for DB projects. The overall combined difference between the subjective metric is 7.7% in favor of DBB.

Table 14 Conclusions

Metric	DB	DBB
Cost Category		
<15MM	• Cost Growth 15.3% lower • Change Order Rate 43.5% lower • Schedule Growth 11.2% lower	• Subjective Indicators 3.7% lower
15MM-50MM	• Change Order Rate 55.6% lower	• Cost Growth 6.5% lower • Schedule Growth 34.1% lower • Subjective Indicators 20.7% lower
>50MM	• Cost Growth 50.9% lower • Change Order Rate 25.0% lower • Schedule Growth 22.0% lower • Subjective Indicators 20.0% lower	
Pricing Method		
Lump Sum	• Cost Growth 31.5% lower • Change Order Rate 65.0% lower	• Schedule Growth 7.8% lower • Subjective Indicators 7.4% lower
Unit Rate	• Schedule Growth 44.6% lower • Change Order Rate 0.0% lower	• Cost Growth 60.7% lower • Subjective Indicators 3.4% lower
Selection Method		
Pre-qualified	• Cost Growth 28.6% lower • Change Order Rate 63.2% lower	• Schedule Growth 10.0% lower • Subjective Indicators 7.1% lower
Open-Low Bid Wins	• Cost Growth 46.5% lower • Change Order Rate 70.0% lower	• Schedule Growth 9.9% lower • Subjective Indicators 0.0% lower
Sole Source	• Cost Growth 1.8% lower • Schedule Growth 60.0% lower • Subjective Indicators 3.7% lower	• Change Order Rate 22.2% lower
Industry Group		
Industrial	• Cost Growth 45.3% lower • Change Order Rate 70.6% lower	• Schedule Growth 7.2% lower • Subjective Indicators 7.4% lower
Commercial	• Change Rate 45.8% lower	• Cost Growth 4.5% lower • Schedule Growth 5.4% lower • Subjective Indicators 7.4% lower

Company Ownership		
Saudi	• Cost Growth 23.6% lower • Change Order Rate 50.0% lower	• Schedule Growth 12.6% lower • Subjective Indicators 7.1% lower
Multi-National	• Cost Growth 25.8% lower • Change Order Rate 28.6% lower • Schedule Growth 2.8% lower	• Subjective Indicators 7.7% lower

7.4 Recommendations

Based on the data analyzed in this thesis the following recommendations are made.

- The project Owner should continue to utilize the DB delivery system for projects expected to fall within the less than $15MM and greater than $50MM categories.

- It is recommended the Owner use the DBB delivery system for projects expected to fall within the range of $15MM to $50MM.

- The data indicate that industrial DB projects will take longer to complete but will cost less with fewer change orders written. Whereas the Owner should consider using the DBB delivery system for commercial projects based on cost and schedule reduction as well as overall lower subjective indicator scores.

7.5 Further Study

The research results have identified areas that require further research. The results identify trends in project performance with different procurement strategies. A larger sample size may allow detection of additional statistically significant differences between delivery systems. This study may also enable further investigation of the impact of the less understood effects of the local geopolitical structure, economy, and culture on the outcome of construction projects. Accordingly, a follow on study that further investigates the impact of project delivery systems on the project performance would be beneficial to owners and contractors.

APPENDIX A

Statistical Notes

Statistical Warning Indicator

When less than 10 projects are included in any table cell, a statistical warning is noted with that data. This notation indicates that data should be interpreted with caution due to the small number of projects represented in those cells.

Removal of Statistical Outliers

The technique used for identifying statistical outliers is the same used to define outliers in most statistical texts. By definition there were no outliers for the 10 soft or subjective performance metrics scored on a scale of 1 – 5.

Data Sensitivity

The responsibility of preserving confidentiality exists to protect the research participant's information. Therefore, all data has been aggregated into totals within a category to ensure that no individual project or the identity of the company contributing data is identifiable in any chart or table presented in this thesis.

APPENDIX B

METRIC DEFINITIONS

The performance factors investigated in this study were evaluated by the field project execution team at regular intervals during the contract period. The scores studied in this thesis are the final evaluation at project completion. A scale of 1 to 5 was used by the project execution team to evaluate the contractor's performance for each of the questions listed in Appendix D and are defined as follows: 1-outstanding, 2-above average, 3-average, 4-below average, and 5-unsatisfactory. The cost growth, schedule growth, and number of contract changes, performance indicators were evaluated using a different criterion defined hereunder.

Cost Growth

The sum of all change order values expressed in US Dollars made against a given contract expressed in percentage.

Number of Contract Changes

The sum of contract change orders made against a given contract expressed as each.

Schedule Growth

Schedule growth is the difference between the planned contract completion date and the actual completed date expressed in percentage.

APPENDIX C

Acknowledgements

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APPENDIX D

DATA COLLECTION QUESTIONANAIRE

Description	1-Outstanding	2-Above Average	3-Average	4-Below Average	5-Unsatisfactory
Management & Administration					
1. Contractor submitted an up to date complete organization chart. All key personnel specified in the chart were adequate, competent, and assigned to the work in a timely manner with full coverage.					
2. Project status and technical requirements are communicated to the owner's site execution team regularly per the contract requirements.					
3. Contractor demonstrated team work and full cooperation.					
4. Obtained all required permits, licenses and other governmental authorizations, necessary to perform the work in a timely manner.					
5. Contractor representative responds in proactive and timely manner to the owner's project execution team's requests and reporting. Communication with contractor's management is open and effective.					

6. Contractor participates in and is sufficiently prepared for regular progress meetings.					
Equipment / Facilities					
1. Condition of construction camps. Are offices are in compliance with contract requirements.					
2. Contractor has complied with inspection requirement for contractor’s equipment and sub-contractor’s equipment.					
3. Construction equipment is available and fit for duty.					
4. Proper certification of operators and equipment were obtained in a timely manner.					
Subcontracting					
1. Subcontracting plan is submitted and approved in a timely manner.					
2. Contractor’s subcontracting plan includes all sub-tier subcontractors.					
3. Subcontractors are mobilized when required to support construction schedule.					
4. Subcontractors are familiar with owner’s standards, specifications, and procedures.					
5. Contractor manages his subcontractors.					
6. Subcontractors are efficient and knowledgeable.					
Planning & Scheduling					
1. Contractor has shown the ability to plan the work and submit schedules in a timely manner.					
2. Construction schedule variance					
3. Adequate and qualified contractor manpower is provided to execute the project.					

4. Review meetings were conducted in a professional manner with action items properly recorded, acted upon, and closed.					
5. Project schedule, logistical plan, and resource plan were followed effectively, with any variances reported to the Owner's project execution team.					
6. Regular reports are submitted in a timely manner.					
7. Contractor effectively plans and anticipates delays to minimize schedule impact.					
Quality					
1. Complied with the project quality standards.					
2. Contractor responded and resolved non-conformance reports in a timely manner.					
3. Contractor has sufficient qualified quality assurance / quality control (QA / QC) inspectors to cover the project scope of work.					
4. Contractor has conducted final testing, inspection and checkout of the facilities.					
5. Contractor's site quality staff are proactive in finding problems prior to Owner's inspection.					
Technical Competency and Workmanship					
1. Contractor's workforce is technically competent, adequate, and capable of coordinating with the Owner's project execution team.					
2. Contractor demonstrates ability to meet special requirements such as heave lift, confined space entry, and so forth.					
3. Contractor is familiar with the project standards, specifications, and procedures.					
Material Procurement					

1. Contractor follows his procurement plan effectively with any deviations promptly addressed and reported.					
2. Material is handled, tested, and stored properly.					
3. Material expeditors are competent and available.					
Cost Control					
1. Invoices are organized, accurate, and submitted in a timely manner.					
2. Invoice supporting documents provided					
3. Cost estimates are good quality, including adequate detail, professional presentation, and timely.					
4. Contractor identifies and proposes value engineering opportunities.					
Safety					
1. Employees wearing and properly using approved personal protective equipment (PPE)					
2. Employees maintain safe minimize fall, striking against, struck by, caught between, hot / cold surfaces, electric current, and / or overexertion.					
3. Uses power and hand tools which are right for the job, being used correctly, and in safe condition.					
4. Mechanical and heavy equipment being used correctly, in a safe operating condition, regularly inspected and maintained.					
5. Employees comply with safety rules and work procedures.					
6. Contractor maintains good housekeeping at work and storage sites.					
7. Conducts and documents safety meeting by Contractor’s site management.					
8. Conduct and document job site safety inspections					

9. Contractor has and practices an emergency response plan.					
10. Contractor personnel are competent and qualified. Utilizes certified crane operators, riggers, scaffolding builders and so forth.					
11. Contractor provides sufficient and qualified field supervision.					
12. Report and investigate incidents and near-misses.					
Loss Prevention					
1. Safety compliance of all employees					
2. Medical coordination and support					
3. Lost time injuries					
4. Motor vehicle accidents					
5. Unsafe driving practice warnings					

APPENDIX E

PERFORMANCE INDICATOR SAMPLE SIZE

Table 15 Sample Size by Project Delivery System

Metric	DB	DBB
Cost Growth (%)	88	204
Change Rate	88	204
Schedule Growth (%)	78	194
Management & Administration	27	148
Equipment / Facilities	28	144
Subcontracting	24	87
Planning & Scheduling	28	147
Quality	28	146
Workmanship	28	147
Material Procurement	27	144
Cost Control	27	138
Safety	28	140
Loss Prevention	13	46

Table 16 Sample Size by Cost Category

Metric	<15MM		15 - 50 MM		>50 MM	
	DB	DBB	DB	DBB	DB	DBB
Cost Growth (%)	33	160	17	23	38	21
Change Rate	33	160	17	23	38	21
Schedule Growth (%)	30	153	16	22	32	19
Management & Administration	22	135	2	9	3	4
Equipment / Facilities	22	131	3	9	3	4
Subcontracting	18	76	3	7	3	4
Planning & Scheduling	22	134	3	9	3	4
Quality	22	133	3	9	3	4
Workmanship	22	134	3	9	3	4
Material Procurement	21	132	3	8	3	4
Cost Control	21	125	3	9	3	4
Safety	22	128	3	9	3	3
Loss Prevention	9	40	1	4	3	2

Table 17 Sample Size by Pricing Method

Metric	Lump Sum		Unit Rate	
	DB	DBB	DB	DBB
Cost Growth (%)	86	195	2	9
Change Rate	86	195	2	9
Schedule Growth (%)	76	187	2	7
Management & Administration	25	141	2	7
Equipment / Facilities	26	137	2	7
Subcontracting	23	85	1	2
Planning & Scheduling	26	140	2	7
Quality	26	139	2	7
Workmanship	26	140	2	7
Material Procurement	25	137	2	7
Cost Control	25	131	2	7
Safety	26	131	2	7
Loss Prevention	12	44	1	2

Table 18 Sample Size by Selection Method

Metric	Pre-qualified		Open-Solicitation		Sole Source	
	DB	DBB	DB	DBB	DB	DBB
Cost Growth (%)	77	180	6	20	5	4
Change Rate	77	180	6	20	5	4
Schedule Growth (%)	67	171	6	19	5	4
Management & Administration	22	137	2	9	3	2
Equipment / Facilities	23	133	2	9	3	2
Subcontracting	20	76	2	9	2	2
Planning & Scheduling	23	136	2	9	3	2
Quality	23	135	2	9	3	2
Workmanship	23	136	2	9	3	2
Material Procurement	22	134	2	9	3	1
Cost Control	22	127	2	9	3	2
Safety	23	129	2	9	3	2
Loss Prevention	10	44	2	2	0	1

Table 19 Sample Size by Industry Group

Metric	Industrial		Commercial	
	DB	DBB	DB	DBB
Cost Growth (%)	65	142	23	62
Change Rate	65	142	23	62
Schedule Growth (%)	58	137	20	57
Management & Administration	14	99	13	49
Equipment / Facilities	15	98	13	46
Subcontracting	12	53	12	34
Planning & Scheduling	15	98	13	49
Quality	15	98	13	48
Workmanship	15	98	13	49
Material Procurement	14	95	13	49
Cost Control	15	90	12	48
Safety	15	93	13	47
Loss Prevention	9	36	4	10

Table 20 Sample Size by Company Ownership

Metric	Saudi Arabian		Multi-National	
	DB	DBB	DB	DBB
Cost Growth (%)	31	162	57	42
Change Rate	31	162	57	42
Schedule Growth (%)	30	154	48	40
Management & Administration	19	135	8	11
Equipment / Facilities	19	131	9	11
Subcontracting	17	75	7	10
Planning & Scheduling	19	134	9	11
Quality	19	133	9	11
Workmanship	19	134	9	11
Material Procurement	19	131	8	11
Cost Control	18	125	9	11
Safety	19	129	9	10
Loss Prevention	8	42	5	4

NOMENCLATURE

Abbreviations

DBB	Design Bid Build
DB	Design Build
PDS	Project delivery system
SAR	Saudi Arabian Riyals
USD	United States Dollars
$	United States Dollars
K	Thousand
MM	Million
B	Billion
μ	Mean
μ_{DBB}	Mean design-bid-build
μ_{DB}	Mean design-build
H_0	Null hypothesis
H_1	Alternate hypothesis

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